

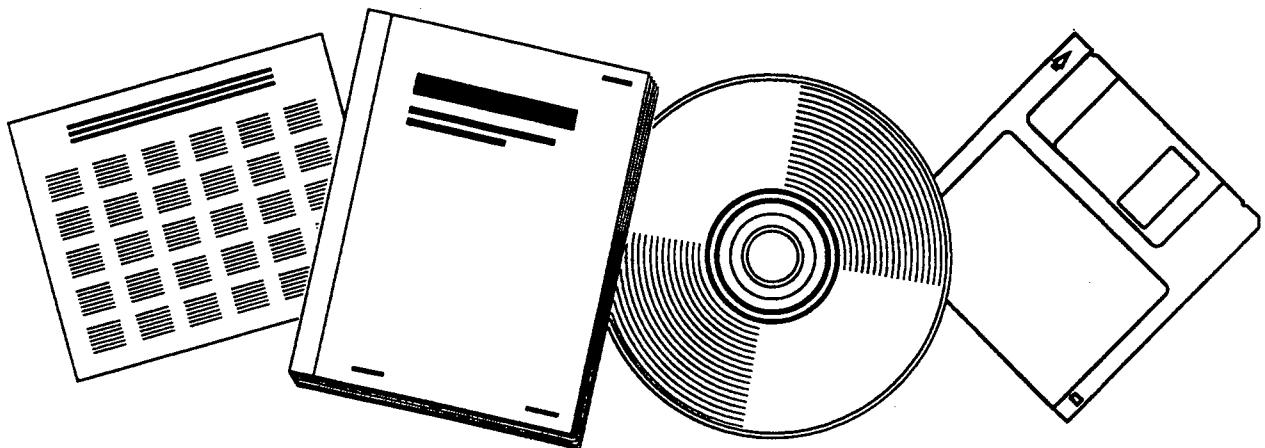


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**STATEWIDE CALIBRATION OF ASPHALT
TEMPERATURE STUDY FROM 1992 AND 1993
VOLUME II: APPENDICES**

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**STATEWIDE CALIBRATION OF
ASPHALT TEMPERATURE STUDY
FROM 1992 AND 1993**

VOLUME II: APPENDICES

by

**Y. Richard Kim, PhD, PE
Associate Professor**

**Sunwoo Park, PhD
Research Associate**

**Lisheng Shao, PhD
Research Associate**

Final Report

November 1997

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**Final Report Submitted to the
North Carolina Department of Transportation**

**Department of Civil Engineering
North Carolina State University
Raleigh, NC**

November 1997

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16. Abstract The overlay design analysis in the 1993 AASHTO Guide for Design of Pavement Structures introduces nondestructive deflection testing as a primary means of evaluating the in situ structural capacity of existing pavements. In order to use the approaches recommended in the AASHTO Guide, deflection measurements or backcalculated layer properties must be corrected to a particular type of loading system and a standard set of environmental conditions. One of the major environmental factors affecting surface deflection measurements of flexible pavements is the pavement temperature.		
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ABSTRACT (CONTINUED)

During the course of this study, FWD tests and temperature measurements have been conducted on seven pavement sections at different regions of North Carolina. The field data obtained from four pavements in the central region during the 92/93 study are also included in the analysis. The new temperature correction procedure is composed of the algorithm predicting the AC layer mid-depth temperature as an effective AC layer temperature and the temperature correction procedure for deflections and backcalculated moduli.

The temperature prediction algorithm is based on fundamental principles of heat transfer and uses the surface temperature history since yesterday morning to predict the AC layer mid-depth temperature at the time of FWD testing today. The surface temperature history is determined using the yesterday's maximum air temperature and cloud condition, the minimum air temperature of today's morning, and surface temperatures measured during FWD tests. For the deflection and modulus correction procedure, a new statewide empirical model is recommended due to its simplicity and practicality. However, it needs to be warned that, when mixture properties are much different from the normal mixtures in North Carolina, this empirical model may lead to erroneous correction. Therefore, whenever thermo-mechanical properties of mixtures are available, the analytical procedure described in this report is strongly recommended, which is based on the theory of viscoelasticity and the time-temperature superposition principle.

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APPENDIX A.1

STATISTICAL ANALYSIS ON THE MAXIMUM AND MINIMUM SURFACE TEMPERATURES

APPENDIX A.1

Pitt County

PNB#	DATE	AIR TEMPERATURE			SURFACE TEMPERATURE			TEMP. DIFFERENCE			TIME			WEATHER INDEX	
		DATE#	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DMAX	DMIN	TIME@MAX	R. @MIN	SUN SET			
09-Feb-96*	35104	22.7	10.796	29.2	0	15.48	9.1	-17.7	0.5003	0.5419	0.5013	0.2802	0.7192	500	
10-Feb-96	35105	-2.1	9.4104	29.6	2	12.3083	6.8	-2.3	0.2919	0.5628	0.0281	0.6432	0.7296	80	
11-Feb-96	35106	4.5	13.8083	28.7	7.1	13.8062	8.6	-2.7	0.9794	0.5211	1.5866	0.5483	0.2789	100	
12-Feb-96	35107	12.8	-2.5	4.0271	22.7	2.3	9.0625	5.6	-2.9	0.2919	0.5419	0.0311	0.5932	0.2782	70
13-Feb-96	35108	11.6	-7.6	2.4337	23.5	-1.7	7.7096	6.2	-3.4	0.2819	0.5628	0.0325	0.6417	0.2775	100
14-Feb-96	35109	13.7	3.6	8.6396	15.8	4.8	9.3875	3.1	-1.9	0.0211	0.5628	-0.5734	0.6413	0.2678	0
15-Feb-96*	35110	11.1	4.8	6.55	10.3	6.8	7.495	1.9	-1.1	0.2919	0.3961	0.0355	0.2683	0.2761	50
16-May-96	35199	23.5	9.2	16.2679	44	17.7	30.5536	7.9	-4.4	0.9378	0.5856	1.279	0.6656	0.1993	100
15-May-96	35200	19.5	4.9	11.9458	27.4	14	18.4292	2.5	-3.7	0.2294	0.4586	0.053	0.4492	0.1988	75
16-May-96	35201	22.7	12.4	17.3979	27	15.9	20.0625	2.4	-2	-0.0114	0.6878	-0.4136	0.8447	0.1983	75
17-May-96	35202	35.9	15.9	24.8229	47	18.6	29.7729	10.5	-1.5	0.2086	0.5003	0.0187	0.521	0.1978	100
18-May-96	35203	41	19.7	27.4354	57.9	22.4	35.475	11.1	-1.7	0.2086	0.5628	0.0195	0.6284	0.1973	100
19-May-96	35204	412	19.7	28.5917	60.3	23.6	37.5375	11.5	-2.5	0.2086	0.5419	0.0202	0.5924	0.1968	100
20-May-96	35205	419	20.2	29.7625	60	24.7	38.3883	10.7	-2.9	0.2086	0.5419	0.0209	0.5921	0.1984	100
21-May-96	35206	39.3	21	29.2	58.9	23.8	38.6662	9.9	-2.6	0.2086	0.5419	0.0216	0.5919	0.1959	100
22-May-96	35207	32.1	17.2	24.6271	46.8	28.2	33.2542	7.3	-3.6	0.9378	0.5211	1.2878	0.5561	0.1955	100
23-May-96	35208	37.9	11.8	23.5833	55.2	20.2	34.1313	10.1	-4.1	0.2086	0.5628	0.0229	0.6289	0.1951	60
24-May-96	35209	37.7	16.5	26.4979	57.6	22.9	36.1975	10.3	-3.1	0.2086	0.5628	0.0235	0.6288	0.1948	100
25-May-96	35210	30.3	18	23.3396	45.2	24.5	33.1125	8.6	-3.9	0.2294	0.5419	0.0295	0.5909	0.1944	100
26-May-96	35211	29.5	15.9	20.6979	41.9	23.2	29.0983	6.2	-2.9	0.9378	0.5211	1.2626	0.5559	0.1941	50
27-May-96*	35212	20.8	17.7	19.0313	24.6	23.1	23.9188	-1	-2.8	-0.0206	0.2711	-0.3634	0.1311	0.1938	75

21 *Incomplete recording day (temperature records less than 24 hours)

Statistical Results

Winter

AVERAGE

STD

Spring

AVERAGE

STD

All Season

AVERAGE

STD

Summer

AVERAGE

STD

Autumn

AVERAGE

STD

Total

AVERAGE

STD

Year

AVERAGE

STD

APPENDIX A.1

Cassia County

CWB										WEATHER INDEX									
DAYS OF RECORDING -		TEMP. DIFFERENCE										TIME							
		AIR TEMPERATURE					SURFACE TEMPERATURE					R.T@MIN		R.T@MAX		SUN RISE		SUN SET	
DATE	DATE#	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DMIN	TIME@MIN	TIME@MAX	R.T@MIN	R.T@MAX	SUN RISE	SUN SET	AM	PM
16-Feb-96	35111	10.2	-2.6	1.8778	13.8	0.8	6.5296	3.1	-4.8	0.987	0.5179	1.6011	0.5368	0.2762	0.7284	500	500	500	500
17-Feb-96	35112	4.4	-6.7	0.0354	13.3	-3.3	2.8896	6.2	-6.0	0.3095	0.4762	0.0755	0.4445	0.2754	0.7271	500	500	500	500
18-Feb-96	35113	10.1	-2.4	3.3875	18.7	-0.6	5.6104	11.9	-4.1	0.2887	0.4762	0.0755	0.4448	0.2747	0.7277	500	500	500	500
19-Feb-96	35114	16.9	-3.1	7.4958	19.1	0.3	8.325	11.1	-3.8	0.1128	0.5179	0.2884	0.5367	0.2739	0.7284	500	500	500	500
20-Feb-96	35115	18.6	3.9	11.6604	15.7	6.1	10.9208	4.5	-2.8	0.0595	0.5178	0.4685	0.5367	0.2731	0.7291	500	500	500	500
21-Feb-96	35116	16.6	5.9	11.8947	25.1	9.7	14.3146	11.7	-0.9	0.247	0.5179	0.0554	0.5368	0.2723	0.7287	500	500	500	500
22-Feb-96	35117	20.1	4.9	11.6938	24.9	7.9	14.4708	9	-2.8	0.1845	0.5595	-0.1897	0.6276	0.2715	0.7304	500	500	500	500
23-Feb-96	35118	20.8	7.5	13.7854	28.5	9.9	16.6729	11.4	-2.4	0.2053	0.5178	-0.1421	0.5369	0.2707	0.731	500	500	500	500
24-Feb-96	35119	25.4	3.8	15.0083	31.1	9.5	17.8021	12.3	-5.3	0.3997	0.5179	1.5746	0.5369	0.2699	0.7317	500	500	500	500
25-Feb-96	35120	19	2.1	10.7354	29.4	5.2	13.675	15.1	-5.4	0.2678	0.4762	-0.0027	0.4447	0.2691	0.7323	500	500	500	500
26-Feb-96	35121	22	8.5	14.4979	28	9.8	16.4854	13.1	-3.1	0.1012	0.4553	-0.3556	0.4026	0.2683	0.733	500	500	500	500
27-Feb-96	35122	21.8	11.7	15.1417	30.6	11.5	17.7063	12	-2.3	0.2053	0.5178	-0.1331	0.5372	0.2674	0.7336	500	500	500	500
28-Feb-96*	35123	21.4	12.9	14.5381	25.3	12.7	14.8149	9.8	-2.1	0.2678	0.4545	0.0027	0.3591	0.2666	0.7342	500	500	500	500
03-Apr-96*	35158	21.3	13.1	16.0308	42.3	15.3	28.0885	16.8	-4.4	0.9365	0.5559	1.465	0.6247	0.2339	0.7544	500	500	500	500
04-Apr-96	35159	22.6	11.3	16.9313	44	12.5	23.9104	16.3	-4.2	0.2257	0.5559	-0.0137	0.6247	0.2329	0.7555	100	100	100	100
05-Apr-96	35160	26.9	9.3	16.8917	40.7	14.4	23.3554	14.3	-3.7	0.5882	0.5349	0.0279	0.5885	0.2319	0.7555	100	100	100	100
06-Apr-96	35161	16.4	5.5	9.2063	24.8	9.8	14.7	6.5	-3.8	0.9665	0.4132	1.4579	0.3437	0.2311	0.7561	-1	-1	-1	-1
07-Apr-96	35162	14.4	0.7	7.2167	30.9	8.4	14.6913	11.5	-4	0.2049	0.5799	-0.0478	0.6843	0.2301	0.7568	-1	0	0	0
08-Apr-96	35163	16	1.6	8.8771	32.8	6	15.75	16.8	-5.3	0.2049	0.434	-0.0459	0.3988	0.2291	0.7572	75	0	0	0
09-Apr-96	35164	14.7	-0.5	8.8958	26.9	7.7	15.4298	7.1	-6.5	0.9549	0.5799	1.3723	0.6641	0.2288	0.7577	0	25	25	25
10-Apr-96	35165	14.4	-1.4	6.2229	34.1	3.7	15.8583	13.2	-6.4	0.184	0.5747	-0.0845	0.5463	0.2273	0.7583	100	100	100	100
11-Apr-96*	35166	17.1	2.4	7.165	25.8	6.3	9.985	12.8	-5.1	0.2049	0.3715	-0.0404	0.2726	0.2264	0.7588	100	100	100	100

APPENDIX A.1

New Hanover County

IN8.txt												IN8.txt														
AIR TEMPERATURE			SURFACE TEMPERATURE			TEMP DIFFER			TIME			WEATHER INDEX			TIME			WEATHER INDEX			TIME					
DATE	DATE#	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DMAX	DMIN	TIME@MAX	R. @MIN	R. @MAX	SUN RISE	SUN SET	AM	NOON	PM	TIME@MAX	R. @MIN	R. @MAX	SUN RISE	SUN SET	AM	NOON	PM	
22-Aug-95*	34933	24.4	20.9	23.9522	52.6	30.6	41.0729	14.8	4.7	0.9569	0.5819	1.3515	0.6552	0.2184	0.7648	0	0	0	0.9569	0.5819	1.3515	0.6552	0.2184	0.7648	0	0
23-Aug-95	34934	22.4	20.8	21.875	50.8	25.1	26.8146	4.3	4.9	0.4152	-0.0223	0.3802	0.6235	0.0536	0.7433	0.2194	0.7631	100	70	90	0	0	0	0	0	
24-Aug-95	34935	33.8	21.7	21.2875	49.2	24.5	34.0792	12	3.7	0.2485	0.6235	0.0536	0.6235	0.0529	0.6674	0.2199	0.7622	100	65	85	0	0	0	0	0	
25-Aug-95	34936	34.1	22.6	21.6438	53.7	26.3	36.3167	14.2	4.5	0.2485	0.5819	0.0529	0.6674	0.2199	0.7622	100	65	85	0	0	0	0	0			
26-Aug-95	34937	22.8	20.8	21.5223	29.3	25.4	27.0146	4.8	3.6	0.5659	-0.0223	0.3613	0.4486	0.0224	0.7614	-1	0	0	0	0	0	0	0	0		
27-Aug-95	34938	30.6	22.8	26.6375	34.6	24.8	27.5271	5.1	3.1	0.2694	0.6868	0.0896	0.6662	0.0220	0.7605	-1	0	0	0	0	0	0	0	0		
28-Aug-95	34939	28.7	22.2	24.9062	32.4	24.7	27.6313	2.5	3.1	0.2485	0.7069	0.0504	0.6214	0.0221	0.7596	-1	0	0	0	0	0	0	0	0		
29-Aug-95	34940	32.8	19.7	25.2271	50.3	21.8	32.9708	13.9	4.6	0.2277	0.6027	0.0108	0.7094	0.0219	0.7587	100	100	100	0	0	0	0	0			
30-Aug-95*	34941	31.1	17.5	21.2955	39.5	22.1	26.2818	10.6	6.1	0.2485	0.4152	0.0488	0.3010	0.0224	0.7578	100	100	500	0	0	0	0	0			
14-Nov-95*	34917	9.8	4.5	6.7631	12.4	7.2	9.6444	-1	4.7	0.9694	0.4485	0.1601	0.4349	0.0251	0.6907	500	100	-1	0	0	0	0	0			
15-Nov-95	35018	16.2	9.0	6.4688	21.2	3.6	10.9042	9.4	6.1	0.2819	0.5735	0.0446	0.7269	0.0259	0.6899	40	50	100	0	0	0	0	0			
16-Nov-95	35019	18	2.8	5.075	24.2	2.6	10.7	10.2	7	0.3027	0.5327	0.0919	0.6783	0.0265	0.6898	100	100	100	0	0	0	0	0			
17-Nov-95	35020	17.6	-1.6	4.8437	23.7	3	10.0375	9.7	-6.1	0.2819	0.5735	0.0416	0.7276	0.0262	0.6894	100	100	100	0	0	0	0	0			
18-Nov-95	35021	18	-0.6	7.4333	21.3	3.7	10.6646	8.4	-5.5	0.2819	0.5527	0.0401	0.6786	0.0264	0.689	90	100	100	0	0	0	0	0			
19-Nov-95	35022	24.4	4.2	11.1688	28.3	7.1	14.2211	12.4	4	0.2819	0.5327	0.0386	0.6787	0.0265	0.6887	100	100	100	0	0	0	0	0			
20-Nov-95	35023	17.6	1.6	8.7354	20.9	5.6	11.9458	6.6	-5.5	0.3027	0.5735	0.0446	0.7281	0.0262	0.6883	85	50	20	0	0	0	0	0			
21-Nov-95	35024	24.2	2.2	13.1667	29.6	9	15.7062	10.8	5.9	0.9902	0.5327	0.0329	0.7282	0.0266	0.6898	100	70	70	0	0	0	0	0			
22-Nov-95	35025	17.2	-2.8	4.4979	23.7	3	10.2833	9.6	-7.3	0.3027	0.5327	0.0326	0.7284	0.0262	0.6874	100	100	100	0	0	0	0	0			
23-Nov-95	35026	20.4	-3.3	9.0521	26.4	2.4	10.0125	11.6	-6.1	0.2819	0.5735	0.0326	0.7284	0.0262	0.6899	100	100	100	0	0	0	0	0			
24-Nov-95	35027	16.9	6.6	11.2146	19	9.7	13.0604	5.3	-3.7	0.3027	0.4902	0.0809	0.5292	0.0264	0.6871	100	100	100	0	0	0	0	0			
25-Nov-95*	35028	7.8	4.4	5.7958	11.2	7.7	9.2417	2.7	-4.2	0.3225	0.011	0.1294	-0.6194	0.0265	0.6869	100	100	100	0	0	0	0	0			
31-Jan-96*	35095	18.2	4.8	7.9764	15.6	10.5	10.7636	3.4	-4.1	0.9176	0.4801	1.4777	0.4503	0.0252	0.7123	100	100	100	0	0	0	0	0			
01-Feb-96	35096	7.3	2.8	4.8646	10.6	5.4	7.5938	0.5	-3.6	0.3134	0.5426	0.0739	0.5015	0.0285	0.713	0	0	0	0	0	0	0	0			
02-Feb-96	35097	5.9	2.7	4.3896	7	4.1	6.8229	2.2	-3.3	0.9801	0.0426	1.6155	-0.551	0.281	0.7137	0	-1	-2	0	0	0	0	0			
03-Feb-96	35098	2.9	-4.3	4.3354	4.2	-1.1	1.3325	-2.9	-4.5	0.9802	0.0217	1.5641	-0.5653	0.2805	0.7144	-2	-2	-2	0	0	0	0	0			
04-Feb-96	35099	-0.4	-9.5	-4.4792	4.8	-4.5	-0.3225	-0.7	-6.5	0.9801	0.6259	0.749	0.749	0.28	0.7151	50	100	100	0	0	0	0	0			
05-Feb-96	35100	4.3	-12.6	-4.4229	13.7	-8.2	0.2188	12.6	-8.1	0.3134	0.5634	0.0779	0.7158	0.0107	0.7158	100	80	50	0	0	0	0	0			
06-Feb-96*	35101	7.2	-9.3	-4.9652	9.1	-5.4	-2.7681	10.1	-6.2	0.9506	0.4592	0.0313	0.4211	0.2789	0.7165	100	100	100	0	0	0	0	0			
02-Mar-96*	35177	32.8	18.4	25.5107	49.1	23.7	37.3	16.5	-5.6	0.9547	0.5547	1.3461	0.6228	0.2139	0.7111	0	75	100	0	0	0	0	0			
03-Mar-96	35178	29.8	16.9	22.9313	47.9	20.4	20.8313	14.7	-4.8	0.2214	0.5547	0.0151	0.6017	0.2131	0.7117	90	100	100	0	0	0	0	0			
04-Mar-96	35179	24.4	7.3	15.9771	46	14	12.3229	15.2	-9.5	0.2422	0.5547	0.0151	0.6017	0.2131	0.7122	65	80	80	0	0	0	0	0			
05-Mar-96	35180	25.5	5.3	16.6729	44.4	13.2	26.9833	15.7	-7.9	0.2422	0.5131	0.0357	0.547	0.2115	0.7128	100	100	100	0	0	0	0	0			
06-Mar-96	35181	28.8	14.9	20.2417	46	18.3	25.7125	15.3	-6.6	0.8464	0.6339	1.1503	0.5484	0.2107	0.7133	50	25	0	0	0	0	0	0			
07-Mar-96	35182	30.5	12.4	20.7958	49.4	11.2	26.9229	16.5	-6.6	0.2096	0.5756	-0.017	0.656	0.211	0.7139	95	95	95	0	0	0	0	0			
08-Mar-96	35183	28.4	11.3	20.0063	47.8	17.5	23.7917	16.5	-5.7	0.2422	0.5339	0.0594	0.5848	0.2092	0.7144	100	100	90	0	0	0	0	0			
09-Mar-96*	35184	30.3	19.2	23.3062	47.1	21.3	28.9667	15	-4.5	0.2214	0.5547	0.0231	0.6222	0.2085	0.7155	0	0	0	0	0	0	0	0			
10-Mar-96	35185	22.9	18.1	20.86	27.4	22	23.52	15	-3.9	0.2214	0.3612	0.0244	0.2859	0.2078	0.7155	15	0	0	0	0	0	0	0			

DAYS OF RECORDING - 37 Incomplete recording day (temperature records less than 24 hours)

Statistical Results

Summer	AVERAGE	0.2416	0.6227	0.0391	0.7657
STD		0.0098	0.0170	0.0200	0.0310
Fall	AVERAGE	0.2911	0.5550	0.0601	0.6898
STD		0.0103	0.0249	0.0233	0.0594
Winter	AVERAGE	0.3134	0.5550	0.0759	0.6279
STD		0.0090	0.0104	0.0020	0.0228
Spring	AVERAGE	0.2233	0.6513	0.0318	0.6152
STD		0.0155	0.0222	0.0216	0.0403
All Season	AVERAGE	0.2671	0.5608	0.0500	0.6114
STD		0.0340	0.0292	0.0226	0.0594

APPENDIX A.1

Durham County

DN8.txt		AIR TEMPERATURE				SURFACE TEMPERATURE				TEMP. DIFFER.				TIME				WEATHER INDEX			
DATE	DATE #	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DMAX	DMIN	TIME @ MIN	TIME @ MAX	R.T @ MAX	SUN RISE	SUN SET	AM	NOON	PM				
11-Aug-95*	34922	35.2	22	29.2269	48.5	29.2	40.2577	13.1	0.9507	0.4924	0.4924	0.3178	0.7717	100	100	100	100				
12-Aug-95	34923	38.9	19.3	28.5437	60.1	25.2	39.7188	17.6	-5.4	0.5757	0.0595	0.6526	0.2089	0.771	100	100	100				
13-Aug-95	34924	41.9	22.2	30.7813	57.7	28.7	41.3729	13.2	-5.3	0.2424	0.6174	0.0586	0.7274	0.2095	0.7702	100	100	100			
14-Aug-95	34925	40.8	24.4	31.5812	60.2	30.2	41.9375	15.1	-5.4	0.2424	0.5757	0.0578	0.6537	0.21	0.7684	100	100	100			
15-Aug-95	34926	38.5	24.4	30.2946	55.9	30.2	40.2979	11.9	-5.5	0.2424	0.5965	0.057	0.6916	0.2106	0.7686	100	100	100			
16-Aug-95	34927	37	23.4	29.4996	58.1	28.5	40.3129	15.3	-5.8	0.2632	0.5549	0.0936	0.6175	0.2111	0.7678	100	100	100			
17-Aug-95	34928	37.7	23.2	30.1792	56.3	28.8	40.075	14.2	-6	0.2424	0.5549	0.0953	0.6118	0.2116	0.767	100	100	100			
18-Aug-95	34929	36.2	23	27.2333	46.3	29.1	34.2225	9.2	-5.9	0.2424	0.4299	0.0545	0.3829	0.2122	0.7682	100	100	100			
30-Oct-95*	35002	24.7	7.1	14.0346	27.5	10.2	17.0308	9.9	-9.8	0.9213	0.5671	0.5077	0.7117	0.2504	0.6954	500	500	500			
31-Oct-95	35003	18.9	8.2	12.875	20.5	10.5	14.1021	3	-7.6	0.2755	0.588	0.0549	0.7594	0.2511	0.6947	30	75	75			
01-Nov-95	35004	20.1	12.7	16.1917	21	13.6	16.8042	3.4	-4.6	0.1286	0.5255	-0.2763	0.6119	0.2518	0.6939	30	40	-1			
02-Nov-95	35005	20.4	16.8	18.7479	20.6	17	18.8438	1.8	-2.3	0.2755	0.4838	0.0522	0.549	0.2525	0.6932	-1	-1	-1			
03-Nov-95	35006	25.7	10	19.1188	27.8	12.2	19.9833	8.7	-9.1	0.9838	0.4838	1.6828	0.5249	0.2531	0.6925	-1	90	100			
04-Nov-95	35007	13.9	-1.1	6.7042	21.3	3.6	10.4937	3.1	-15.1	0.9005	0.5463	1.4762	0.6677	0.2538	0.6919	100	100	100			
05-Nov-95	35008	10.5	-4	3.2979	14.8	-0.8	6.9875	1.1	-15.5	0.4421	0.479	0.4396	0.6912	0.2545	0.6912	100	80	100			
06-Nov-95*	35009	16	-1.9	2.9	19.4	0.9	5.8933	7.1	-13.1	0.2546	0.4838	-0.0013	0.5225	0.2552	0.6906	100	100	100			
23-Jan-96*	35087	8.6	4.2	5.4452	9.1	6	6.7727	-0.4	-2.2	0.9447	0.7781	1.1612	1.1624	0.2839	0.7019	500	500	75			
24-Jan-96	35088	19.4	3.5	12.0854	15.8	4	9.3896	7.3	-5.5	0.9884	0.6114	1.6774	0.7026	0.2836	0.7026	50	30	70			
25-Jan-96	35089	11.3	-4.8	2.2	19.2	-0.8	5.6229	12.4	-8	0.2781	0.5906	-0.0123	0.7316	0.2832	0.7033	100	100	100			
26-Jan-96	35090	14.7	-7.4	5.525	16	-2.4	6.2771	10.7	-8.3	0.1947	0.5906	-0.2091	0.7306	0.2828	0.704	100	80	-1			
27-Jan-96	35091	19.1	0.4	12.1479	18.8	3	11.0812	8.6	-7.1	0.9864	0.6114	1.6668	0.7789	0.2824	0.7048	50	50	50			
28-Jan-96	35092	11.7	-4.9	1.9042	20.7	-1.6	6.2333	14	-8.9	0.2989	0.5697	0.0399	0.6794	0.282	0.7055	100	100	-100			
29-Jan-96*	35093	4.9	-3	1.4208	6.4	-1	3.3209	0	-6	0.2364	0.5489	-0.1063	0.6195	0.2815	0.7062	10	-1	-1			
30-Jan-96*	35094	9.6	0.8	5.2405	11	2.8	6.3324	4.9	-3.6	0.2156	0.6114	-0.1538	0.7756	0.2811	0.7071	70	50	50			
DAYS OF RECORDING =		24	* Incomplete recording day (temperature records less than 24 hours)																		
Statistical Results																					
Summer																					
AVERAGE										0.2459		0.5792		0.636		0.6601					
STD										0.0078		0.0222		0.0135		0.0392					
Fall																					
AVERAGE										0.2755		0.5046		0.0517		0.5713					
STD										0.0000		0.0614		0.0029		0.1386					
Winter																					
AVERAGE										0.2520		0.5750		-0.0720		0.6928					
STD										0.0400		0.0173		0.0949		0.0422					
All Season																					
AVERAGE										0.2546		0.5607		0.0192		0.6497					
STD										0.0257		0.0462		0.0811		0.0879					

APPENDIX A.1

Polk County

On 1st	AIR TEMPERATURE										SURFACE TEMPERATURE										TEMP. DIFFERENCE										WEATHER INDEX													
	DATE	DATE#	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DMAX	DMIN	TIME@MAX	RT@MIN	SUN RISE	SUN SET	AM	NOON	PM	DATE	DATE#	DAY MAX	DAY MIN	DAY MEAN	DMAX	DMIN	TIME@MAX	RT@MIN	SUN RISE	SUN SET	AM	NOON	PM										
07-Feb-96*	35102	14.8	2.8	7.775	21.5	5.5	12.1375	11.4	-1.6	0.9871	0.5496	1.8467	0.6446	0.2681	0.7047	500	100	50	07-Feb-96*	35103	16.3	2.6	9.1125	16.7	4.1	8.6917	6.7	-1.4	0.2787	0.5496	0.0257	0.8441	0.2675	0.7054	30	65	45							
08-Feb-96	35104	19.8	5.1	11.7104	29	5.5	13.725	10.4	-2.1	0.2986	0.5704	0.0745	0.691	0.2668	0.7062	100	100	100	09-Feb-96	35105	26	-1.9	12.0708	33.2	2.6	14.7208	12.6	-3.6	0.2996	0.5912	0.0757	0.7376	0.2662	0.7069	100	100	100							
10-Feb-96	35106	20	2	11.7229	32	3.2	15.3167	9.4	-4.9	0.9871	0.5912	1.6322	0.7368	0.2655	0.7076	100	100	100	11-Feb-96	35107	8.9	-1	2.5229	19.8	1.1	7.6146	5.9	-4.4	0.9871	0.5912	1.6287	0.7248	0.2648	0.7083	2	25	25							
12-Feb-96	35108	14.6	-1.9	5.2979	26.6	-0.9	9.3771	9.3	-3.7	0.2986	0.5912	0.0797	0.7353	0.2641	0.7079	100	100	100	13-Feb-96	35109	2.2	6.6667	15.5	4	6.6542	6.1	-3.1	0.1954	0.4652	0.1524	0.7097	0.2634	0.7097	50	100	100								
14-Feb-96*	35110	20.4	5.5	11.4577	28.4	9.1	17.1923	10.6	-3.6	0.5857	0.5212	1.4224	0.5799	0.2208	0.7388	500	20	100	01-Apr-96*	35116	22.9	0.1	11.2458	39.6	3.7	18.7542	13.9	-4.3	0.2503	0.5628	0.0588	0.6802	0.2198	0.7394	100	100	100							
02-Apr-96	35117	32.1	-1.2	15.8167	46.2	5.6	22.5479	15.1	-4.8	0.2712	0.6045	0.1004	0.7401	0.2188	0.7389	100	100	100	03-Apr-96	35118	34.9	10.2	20.6587	47.9	13.7	26.8646	14.5	-3.7	0.167	0.5837	0.0973	0.6599	0.2179	0.7405	100	100	100							
04-Apr-96	35119	24.7	5.6	14.4854	47.5	12.7	25.2312	13.8	-4.6	0.2712	0.5837	0.1035	0.6599	0.2179	0.7405	100	100	100	05-Apr-96	35120	10.4	4	7.0063	17.7	9.4	13.2813	1.3	-4.1	0.9795	0.5837	1.4525	0.6695	0.216	0.7416	60	40	-1							
06-Apr-96	35121	16.5	-1.2	6.2312	38.4	6.1	19.1563	9.8	-4.3	0.5628	0.5275	0.0215	0.6598	0.215	0.7422	100	100	100	07-Apr-96	35122	15.5	4.1	7.8708	23.9	9.9	14.3521	6.4	-3.7	0.9378	0.417	1.3639	0.2141	0.7427	50	50	-1								
08-Apr-96	35123	13.6	1.3	7.9896	35.5	4.6	16.4922	10	-4.8	0.2295	0.5442	0.0308	0.6203	0.2131	0.7433	100	100	100	09-Apr-96	35124	9.7	-2	2.1444	13.3	3.4	5.85	3.2	-5.4	0.2087	0.3128	-0.0087	0.1892	0.2122	0.7439	100	100	100							
DAYS OF RECORDING = 18										* Incomplete recording day (temperature records less than 24 hours)																																		
STATISTICAL RESULTS																																												
Winter																																												
AVERAGE																																												
STD																																												
Spring																																												
All Season																																												
AVERAGE																																												
STD																																												

WNB.IRD		AIR TEMPERATURE				SURFACE TEMPERATURE				TEMP. DIFFERENCE				TIME				WEATHER INDEX		
DATE	DATE#	DAY MAX	DAY MIN	DAY MEAN	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	DAY MEAN	DAY MAX	DAY MIN	RT @MAX	R. @MIN	SUN RISE	SUN SET	AM NOON	PM
21-Aug-95*	34932	39	20.6	28.48715	53.6	28	40.5	14.5	-6.1	0.9425	0.5467	0.6165	0.207	0.758	500	100	100	100	100	100
22-Aug-95	34933	41.9	17.5	28.2533	55	22.8	35.0093	15.1	-6.2	0.225	0.5675	0.655	-	0.2015	0.7572	100	100	100	100	100
23-Aug-95	34934	31.4	15.4	22.4187	41.5	22.1	30.5082	6.8	-6.8	0.255	0.505	0.0864	0.2081	0.5417	0.5653	80	60	80	60	60
24-Aug-95	34935	37.6	17.7	25.1354	47.7	22.9	31.725	10.9	-5.2	0.255	0.6092	0.0848	0.2086	0.7326	0.7534	90	80	80	80	80
25-Aug-95	34936	37.1	17.4	24.6104	50.1	22.9	32.4917	12.7	-5.5	0.2133	0.5675	0.0077	0.2092	0.7545	0.7545	80	100	100	100	100
26-Aug-95	34937	21.4	19.1	20.0417	25.3	21.3	22.6979	-5.9	-3.8	0.9008	-0.0367	1.2109	-0.453	0.2097	0.7535	-1	-1	-1	-1	-1
27-Aug-95	34938	22.1	19.7	20.6771	23.4	21.1	22.0271	-1.4	-3.6	0.0833	0.6717	-0.2248	-0.8508	0.2103	0.7526	-1	-1	-1	-1	-1
28-Aug-95	34939	34	17.3	23.7438	41.2	20.7	30.2875	14.3	-3.4	0.1171	0.5883	-0.0723	0.698	0.2114	0.7517	40	65	90	30	100
29-Aug-95	34940	36.5	15.7	22.1687	52.5	20.9	33.225	16.6	-4.7	0.2342	0.5467	0.0423	0.6217	0.2114	0.7508	30	100	100	100	100
30-Aug-95*	34941	34.9	17	22.1687	49.7	21.9	29.1	15.2	-5.4	0.255	0.505	0.0802	0.5449	0.2119	0.7498	100	100	100	100	100
30-Oct-95*	35002	19	6.5	12.044	26	11	17.309	10.9	-3.6	0.9798	0.5213	1.6561	0.6231	0.2448	0.6885	500	60	40	60	40
31-Oct-95	35003	11.8	6.6	9.1437	13	9.6	11.1563	-0.7	-3.2	0.2921	0.5005	0.1054	0.5765	0.2455	0.6878	-1	-1	-1	-1	-1
01-Nov-95	35004	20.3	9.9	14.3833	26	11.3	16.8521	8.9	-1.9	0.0005	0.5005	-0.5374	0.5768	0.2462	0.687	40	75	5	75	5
02-Nov-95	35005	18.8	14.5	16.3104	19.6	15.4	17.1521	2	-1.2	0.2921	0.6463	0.103	0.5089	0.2469	0.6863	-1	-1	-1	-1	-1
03-Nov-95	35006	22.2	3.9	15.2083	22.7	10.1	16.8458	4	-5.8	0.0796	0.6255	1.6712	0.8627	0.2476	0.6856	-1	-1	-1	-1	-1
04-Nov-95	35007	13.4	-4.8	2.6582	21	2.3	9.2458	7.5	-7.2	0.0796	0.4588	1.6749	0.4821	0.2483	0.6842	100	100	100	100	100
05-Nov-95	35008	7.6	-7.8	-0.052	13.4	-1.1	5.2804	3.2	-7.2	0.2713	0.5653	0.0513	0.7213	0.249	0.6842	100	100	100	100	100
06-Nov-95*	35009	13.4	-5.2	0.563	19.2	-0.6	5.3662	10.4	-6	0.3921	0.4583	0.0978	0.4819	0.2497	0.6836	100	100	100	100	100
23-Jan-96	35039	4.1	-1.9	1.3038	5.9	1.5	3.1192	3.3	-1.5	0.9832	0.6092	1.6715	0.7849	0.2761	0.6991	500	15	1	1	1
30-Jan-96	35034	6.2	-1.7	2.9104	9.2	0.3	3.9792	4.3	-2.2	0.1498	0.6707	-0.2966	0.9311	0.2757	0.6999	-1	5	5	5	5
31-Jan-96	35035	9.6	-3.3	3.2271	14.9	0.9	6.8979	7.6	-4.2	0.9623	0.5679	1.6151	0.7337	0.2752	0.6985	-1	40	80	40	80
01-Feb-96	35036	1.6	-1.9	-1.0042	5.3	0.3	1.8804	1.6	-2.7	0.9832	0.5873	1.6803	0.7327	0.2146	0.6949	100	100	100	100	100
02-Feb-96	35037	0.1	-4.9	-1.5208	1	-0.7	0.0125	-1	-2.5	0.8165	0.4623	1.2872	0.4388	0.2241	0.7021	-2	-2	-2	-2	-2
03-Feb-96	35038	-0.9	-13	-5.5375	-6.7	-6.4	-2.0042	-2.2	-6	0.9832	0.0004	1.6528	-0.6279	0.2336	0.7029	-2	-2	-2	-2	-2
04-Feb-96	35039	-2.4	-19.8	-12.6146	-4.7	-12.5	-6.5854	6	-7.4	0.9832	0.5973	1.6491	0.73	0.273	0.7036	100	100	100	100	100
05-Feb-96	35100	-2.6	-2.4	-14.0021	4.2	-16.3	-7.3417	6.1	-8	0.2921	0.2915	0.5659	0.6008	0.2724	0.7044	100	50	15	50	15
06-Feb-96*	35101	0.1	-16.4	-12.3865	7.2	-10.9	-7.8955	10.6	-5.2	0.1915	0.4623	-0.1853	0.4397	0.2118	0.7051	100	100	100	100	100
22-Apr-96	35177	33	22.2	26.4542	45.5	23.4	34.4657	16.3	-2.9	0.9379	0.5837	1.3548	0.6915	0.2093	0.7635	500	10	10	10	10
23-Apr-96	35178	26.2	9.6	19.0354	38	13.9	23.9146	10.7	-6.9	0.9379	0.3329	1.3329	0.578	0.2022	0.7541	10	50	10	50	10
24-Apr-96	35179	25.5	1.4	13.0875	46.3	7.9	23.3917	17.2	-7.2	0.5829	0.0886	0.6533	0.2013	0.7547	100	100	100	100	100	
25-Apr-96	35180	28.2	1.4	15.4875	46.1	9.5	24.8625	16.3	-6.8	0.2504	0.5229	0.0899	0.6531	0.2005	0.7653	100	100	100	100	100
26-Apr-96	35181	26.3	9.2	15.7813	38	13.6	20.9687	13.4	-5.2	0.3662	0.6254	0.1997	0.6533	0.1997	0.7559	-1	-1	-1	-1	-1
27-Apr-96	35182	26.4	2.4	14.3896	46.1	9.5	25.05	15.2	-6.7	0.2504	0.5317	0.0823	0.6533	0.1989	0.7565	100	100	100	100	100
28-Apr-96	35183	28.9	0.4	15.3688	44.9	9.4	24.0634	16.1	-7.5	0.2295	0.5452	0.0563	0.6153	0.1981	0.7571	100	100	100	100	100
29-Apr-96	35184	31.5	16.5	21.2654	45.4	18.6	26.1437	14.6	-3.3	0.2504	0.5837	0.0847	0.6895	0.1973	0.7577	10	50	-1	50	500
30-Apr-96*	35185	18.4	10.3	15.0526	36.3	14.5	19.2222	14.1	-5.2	0.3545	0.5004	0.2813	0.5409	0.1965	0.7583	-1	50	500	50	500

Days of RECORDING = 36 * incomplete recording day (temperature records less than 24 hours)

Statistical Results

Summer	AVERAGE	0.2425	0.5552	0.0614	0.6416
STD	STD	0.0167	0.0339	0.0316	0.0618
Fall	AVERAGE	0.2713	0.5630	0.0513	0.7213
STD	STD	0.0000	0.0000	0.0000	0.0000
Winter	AVERAGE	0.2957	0.5655	0.0539	0.8808
STD	STD	0.0000	0.0000	0.0000	0.0000
Spring	AVERAGE	0.2482	0.5670	0.0844	0.6693
STD	STD	0.0084	0.0156	0.0142	0.0278
All Season	AVERAGE	0.2569	0.5634	0.0695	0.6693
STD	STD	0.0196	0.0243	0.0259	0.0490

APPENDIX A.2

SUN RISE AND SUN SET TIMES

USE AND LIMITS OF TABLES

The tables in this collection may be used in any year of the twentieth century and within the geographical boundary of the stated place with an error not exceeding 2 minutes and generally less than 1 minute. A particular table may also be used anywhere in the vicinity of the stated place with an additional error of less than 1 minute for *each nine miles*, reckoned from the station of the U.S. Weather Bureau for the stated place, or reckoned from the nearest boundary in cases when no station of the Weather Bureau existed for the stated place.

Tables are provided for almost all stations of the U.S. Weather Bureau, and all cities of over 50,000 population (1950 census) which are sufficiently remote from other cities of like size to require a separate computation.

The standard time shown is in conformity with time zone boundaries specified by the Interstate Commerce Commission as of 1 June 1962.

Eastern Standard Time is the local time of the 75th meridian. Central Standard Time is the local time of the 90th meridian. Mountain Standard Time is the local time of the 105th meridian. Pacific Standard Time is the local time of the 120th meridian.

Sunrise and sunset are considered to occur when the upper edge of the disk of the Sun appears to be exactly on the horizon. The times of sunrise and sunset given in each table are for an unobstructed horizon, with normal atmospheric conditions, at zero elevation above the Earth's surface in a level region.

The computations are based on a constant semidiameter of the Sun of 16 minutes of arc, an adopted refraction at the horizon of 34 minutes of arc, and the path of the Sun for the year 1966.

Should greater precision be required, corrections for elevation of the observer, angular elevation of the visible horizon, deviations from standard atmospheric conditions, and for a specific year may be derived from *Tables of Sunrise, Sunset and Twilight, Supplement to the American Ephemeris, 1946*, obtainable from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

SUNRISE AND SUNSET AT ASHEVILLE, NORTH CAROLINA
EASTERN STANDARD TIME

NO. 12

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 40	5 28	7 30	5 58	7 00	6 25	6 17	6 52	5 39	7 16	5 16	7 40	5 18	7 50	5 38	7 34	6 02	6 58	6 25	6 14	6 52	5 35	7 21	5 17
2	7 40	5 29	7 30	5 59	6 59	6 26	6 16	6 58	5 38	7 17	5 15	7 41	5 18	7 51	5 39	7 33	6 03	6 56	6 26	6 13	6 53	5 34	7 22	5 17
3	7 40	5 29	7 29	6 00	6 58	6 27	6 14	6 53	5 36	7 18	5 15	7 41	5 19	7 50	5 39	7 33	6 03	6 55	6 26	6 11	6 54	5 33	7 23	5 17
4	7 40	5 30	7 28	6 01	6 57	6 28	6 13	6 54	5 35	7 17	5 15	7 42	5 19	7 49	5 40	7 32	6 04	6 54	6 27	6 10	6 55	5 32	7 24	5 17
5	7 40	5 31	7 27	6 02	6 55	6 29	6 12	6 55	5 34	7 20	5 15	7 43	5 20	7 49	5 41	7 31	6 05	6 52	6 28	6 09	6 56	5 31	7 25	5 17
6	7 40	5 32	7 26	6 03	6 54	6 30	6 10	6 56	5 33	7 21	5 14	7 43	5 20	7 49	5 42	7 30	6 06	6 51	6 29	6 07	6 57	5 31	7 25	5 17
7	7 40	5 33	7 25	6 04	6 52	6 31	6 09	6 56	5 32	7 21	5 14	7 44	5 21	7 49	5 43	7 29	6 06	6 49	6 30	6 06	6 58	5 30	7 26	5 17
8	7 40	5 34	7 24	6 05	6 51	6 31	6 07	6 57	5 31	7 22	5 14	7 44	5 21	7 49	5 43	7 28	6 07	6 48	6 30	6 04	6 59	5 29	7 27	5 17
9	7 40	5 35	7 23	6 06	6 50	6 32	6 06	6 57	5 31	7 23	5 14	7 45	5 22	7 48	5 44	7 26	6 08	6 46	6 31	6 03	7 00	5 28	7 28	5 17
10	7 40	5 35	7 22	6 07	6 48	6 33	6 05	6 59	5 30	7 24	5 14	7 45	5 23	7 48	5 45	7 25	6 09	6 45	6 32	6 02	7 01	5 27	7 29	5 17
11	7 40	5 36	7 21	6 08	6 47	6 34	6 03	7 00	5 29	7 25	5 14	7 46	5 23	7 48	5 46	7 24	6 09	6 44	6 33	6 00	7 02	5 26	7 29	5 17
12	7 40	5 37	7 20	6 09	6 46	6 35	6 02	7 01	5 28	7 25	5 14	7 46	5 24	7 47	5 46	7 23	6 10	6 42	6 34	5 59	7 03	5 26	7 30	5 17
13	7 40	5 38	7 19	6 10	6 44	6 36	6 01	7 01	5 27	7 26	5 14	7 46	5 24	7 47	5 47	7 22	6 11	6 41	6 35	5 58	7 04	5 25	7 31	5 18
14	7 40	5 39	7 18	6 11	6 43	6 37	5 59	7 02	5 26	7 27	5 14	7 47	5 25	7 46	5 48	7 21	6 12	6 39	6 35	5 56	7 05	5 24	7 32	5 18
15	7 39	5 40	7 17	6 12	6 41	6 37	5 58	7 03	5 25	7 28	5 14	7 47	5 26	7 46	5 49	7 20	6 12	6 38	6 36	5 55	7 06	5 24	7 32	5 18
16	7 39	5 41	7 16	6 13	6 40	6 38	5 57	7 04	5 25	7 29	5 14	7 48	5 26	7 46	5 50	7 19	6 13	6 36	6 37	5 54	7 07	5 23	7 33	5 19
17	7 39	5 42	7 15	6 14	6 39	6 39	5 55	7 05	5 24	7 29	5 14	7 48	5 27	7 45	5 50	7 17	6 14	6 35	6 38	5 53	7 08	5 22	7 34	5 19
18	7 38	5 43	7 14	6 15	6 37	6 40	5 54	7 06	5 23	7 30	5 14	7 48	5 28	7 45	5 51	7 16	6 15	6 33	6 39	5 51	7 09	5 22	7 34	5 19
19	7 38	5 44	7 13	6 16	6 36	6 41	5 53	7 06	5 22	7 31	5 14	7 48	5 28	7 44	5 52	7 15	6 15	6 32	6 40	5 50	7 10	5 21	7 35	5 20
20	7 38	5 45	7 12	6 17	6 34	6 42	5 52	7 07	5 22	7 32	5 14	7 49	5 29	7 43	5 53	7 14	6 16	6 30	6 41	5 49	7 11	5 21	7 35	5 20
21	7 37	5 46	7 10	6 18	6 33	6 42	5 50	7 08	5 21	7 33	5 15	7 48	5 30	7 43	5 53	7 12	6 17	6 29	6 42	5 48	7 12	5 20	7 36	5 21
22	7 37	5 47	7 09	6 19	6 31	6 43	5 49	7 09	5 21	7 33	5 15	7 49	5 30	7 42	5 54	7 11	6 18	6 27	6 42	5 46	7 13	5 20	7 36	5 21
23	7 36	5 48	7 08	6 20	6 30	6 44	5 48	7 10	5 20	7 34	5 15	7 49	5 31	7 41	5 55	7 10	6 19	6 26	6 43	5 45	7 13	5 19	7 37	5 22
24	7 36	5 49	7 07	6 21	6 29	6 45	5 47	7 11	5 19	7 35	5 15	7 49	5 32	7 41	5 56	7 09	6 19	6 24	6 44	5 44	7 14	5 19	7 37	5 22
25	7 35	5 50	7 06	6 21	6 27	6 46	5 45	7 11	5 19	7 35	5 16	7 50	5 33	7 40	5 57	7 07	6 20	6 23	6 45	5 43	7 15	5 19	7 38	5 23
26	7 34	5 51	7 04	6 22	6 26	6 47	5 44	7 12	5 18	7 36	5 16	7 50	5 33	7 39	5 57	7 06	6 21	6 22	6 46	5 42	7 16	5 18	7 38	5 23
27	7 34	5 52	7 03	6 23	6 24	6 47	5 43	7 13	5 18	7 37	5 16	7 50	5 34	7 39	5 58	7 05	6 22	6 20	6 47	5 41	7 17	5 18	7 38	5 24
28	7 33	5 53	7 02	6 24	6 23	6 48	5 42	7 14	5 17	7 38	5 17	7 50	5 35	7 38	5 59	7 03	6 22	6 19	6 48	5 39	7 18	5 18	7 39	5 25
29	7 33	5 55	7 01	6 25	6 21	6 49	5 41	7 15	5 17	7 38	5 17	7 50	5 36	7 37	5 60	7 01	6 24	6 16	6 49	5 38	7 19	5 17	7 39	5 25
30	7 32	5 56	6 20	6 50	5 40	7 16	5 17	7 39	5 17	7 50	5 36	7 36	5 60	7 01	6 24	6 16	6 50	5 37	7 20	5 17	7 39	5 26	7 39	5 26
31	7 31	5 57	6 19	6 51	5 51	7 40	5 16	7 40	5 37	7 35	6 01	6 59	5 37	7 35	6 01	6 59	6 51	5 36	7 40	5 27	7 40	5 27	7 40	5 27

Add one hour for Daylight Saving Time if and when in use.

SUNRISE AND SUNSET AT CAPE HATTERAS, NORTH CAROLINA
EASTERN STANDARD TIME

NO. 12

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 11	5 01	7 02	5 30	6 32	5 58	5 49	6 23	5 11	6 48	4 49	7 11	4 51	7 21	5 11	7 06	5 34	6 29	5 57	5 46	6 23	5 08	6 52	4 50
2	7 11	5 02	7 01	5 31	6 31	5 58	5 48	6 24	5 10	6 49	4 48	7 12	4 51	7 21	5 11	7 05	5 35	6 28	5 54	6 24	5 07	6 53	4 50	
3	7 11	5 02	7 00	5 32	6 30	5 59	5 47	6 25	5 09	6 49	4 48	7 13	4 52	7 21	5 12	7 04	5 36	6 27	5 58	5 44	6 25	5 06	6 54	4 50
4	7 11	5 03	6 59	5 33	6 28	6 00	5 45	6 26	5 08	6 50	4 48	7 13	4 52	7 21	5 13	7 03	5 37	6 25	5 59	5 42	6 26	5 05	6 55	4 50
5	7 12	5 04	6 59	5 34	6 27	6 01	5 44	6 27	5 07	6 51	4 48	7 14	4 53	7 20	5 14	7 02	5 37	6 24	5 51	6 41	6 27	5 04	6 56	4 50
6	7 12	5 05	6 58	5 35	6 26	6 02	5 42	6 27	5 06	6 52	4 47	7 14	4 53	7 20	5 15	7 01	5 38	6 23	6 01	5 39	6 28	5 03	6 57	4 50
7	7 12	5 06	6 57	5 36	6 24	6 03	5 41	6 28	5 05	6 53	4 47	7 15	4 54	7 20	5 15	7 00	5 39	6 21	6 01	5 38	6 29	5 02	6 57	4 50
8	7 12	5 07	6 56	5 37	6 23	6 04	5 40	6 29	5 04	6 54	4 47	7 15	4 54	7 20	5 16	6 59	5 40	6 20	5 37	6 30	5 01			

SUNRISE AND SUNSET AT CHARLOTTE, NORTH CAROLINA
EASTERN STANDARD TIME

NO. 12C

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M. P.M.	Set A.M. P.M.																						
1	7 32 5 22	7 23 5 52	6 54 6 19	6 11 6 45	5 33 7 09	5 10 7 33	5 13 7 42	5 32 7 27	5 56 6 51	6 18 6 08	6 45 5 29	7 14 5 12												
2	7 33 5 23	7 22 5 53	6 52 6 20	6 10 6 46	5 32 7 10	5 10 7 33	5 13 7 42	5 33 7 26	5 57 6 50	6 19 6 07	6 46 5 28	7 15 5 12												
3	7 33 5 24	7 22 5 54	6 51 6 21	6 08 6 47	5 31 7 11	5 10 7 34	5 13 7 42	5 34 7 25	5 57 6 48	6 20 6 05	6 47 5 28	7 15 5 11												
4	7 33 5 25	7 21 5 55	6 50 6 22	6 07 6 47	5 30 7 12	5 10 7 35	5 14 7 42	5 35 7 24	5 58 6 47	6 21 6 04	6 48 5 27	7 16 5 11												
5	7 33 5 26	7 20 5 56	6 49 6 23	6 05 6 48	5 29 7 13	5 09 7 35	5 14 7 42	5 35 7 23	5 59 6 45	6 21 6 02	6 49 5 26	7 17 5 11												
6	7 33 5 26	7 19 5 57	6 47 6 23	6 04 6 49	5 28 7 13	5 09 7 36	5 15 7 42	5 36 7 22	5 60 6 44	6 22 6 01	6 50 5 25	7 18 5 11												
7	7 33 5 27	7 18 5 58	6 46 6 24	6 03 6 50	5 27 7 14	5 09 7 36	5 15 7 41	5 37 7 21	5 60 6 43	6 23 6 00	6 51 5 24	7 19 5 11												
8	7 33 5 28	7 17 5 59	6 45 6 25	6 01 6 51	5 26 7 15	5 09 7 37	5 16 7 41	5 38 7 20	5 61 6 41	6 24 5 58	6 52 5 23	7 20 5 11												
9	7 33 5 29	7 16 6 00	6 43 6 26	6 00 6 51	5 25 7 16	5 09 7 37	5 17 7 41	5 38 7 19	5 62 6 40	6 25 5 57	6 53 5 22	7 20 5 12												
10	7 33 5 30	7 15 6 01	6 42 6 27	5 59 6 52	5 24 7 17	5 09 7 38	5 17 7 41	5 39 7 18	5 63 6 38	6 25 5 56	6 53 5 21	7 21 5 12												
11	7 33 5 31	7 14 6 02	6 40 6 28	5 57 6 53	5 23 7 17	5 09 7 38	5 18 7 40	5 40 7 17	6 03 6 37	6 26 5 54	6 54 5 21	7 22 5 12												
12	7 33 5 32	7 13 6 03	6 39 6 29	5 56 6 54	5 22 7 18	5 08 7 39	5 18 7 40	5 41 7 16	6 04 6 35	6 27 5 53	6 55 5 20	7 23 5 12												
13	7 32 5 33	7 12 6 04	6 38 6 29	5 55 6 55	5 21 7 19	5 08 7 39	5 19 7 40	5 42 7 15	6 05 6 34	6 28 5 52	6 56 5 19	7 23 5 12												
14	7 32 5 34	7 11 6 05	6 36 6 30	5 53 6 55	5 21 7 20	5 08 7 39	5 20 7 39	5 42 7 14	6 05 6 33	6 29 5 50	6 57 5 19	7 24 5 13												
15	7 32 5 35	7 10 6 06	6 35 6 31	5 52 6 56	5 20 7 21	5 09 7 40	5 20 7 39	5 43 7 13	6 06 6 31	6 30 5 49	6 58 5 18	7 25 5 13												
16	7 32 5 36	7 09 6 07	6 34 6 32	5 51 6 57	5 19 7 21	5 09 7 40	5 21 7 38	5 44 7 12	6 07 6 30	6 30 5 48	6 59 5 17	7 25 5 13												
17	7 31 5 37	7 08 6 08	6 32 6 33	5 49 6 58	5 18 7 22	5 09 7 40	5 22 7 38	5 45 7 10	6 08 6 28	6 31 5 46	7 00 5 17	7 26 5 14												
18	7 31 5 38	7 07 6 09	6 31 6 34	5 48 6 59	5 18 7 23	5 09 7 41	5 22 7 37	5 45 7 09	6 08 6 27	6 32 5 45	7 01 5 16	7 27 5 14												
19	7 31 5 39	7 06 6 10	6 29 6 34	5 47 6 59	5 17 7 24	5 09 7 41	5 23 7 37	5 46 7 08	6 09 6 25	6 33 5 44	7 02 5 16	7 27 5 14												
20	7 30 5 40	7 05 6 11	6 28 6 35	5 46 7 00	5 16 7 24	5 09 7 41	5 24 7 36	5 47 7 07	6 10 6 24	6 34 5 43	7 03 5 15	7 28 5 15												
21	7 30 5 41	7 04 6 12	6 26 6 36	5 44 7 01	5 16 7 25	5 09 7 41	5 24 7 35	5 48 7 05	6 11 6 22	6 35 5 42	7 04 5 15	7 28 5 15												
22	7 29 5 42	7 02 6 13	6 25 6 37	5 43 7 02	5 15 7 26	5 10 7 42	5 25 7 35	5 48 7 04	6 11 6 21	6 36 5 40	7 05 5 14	7 29 5 16												
23	7 29 5 43	7 01 6 14	6 24 6 38	5 42 7 03	5 14 7 27	5 10 7 42	5 26 7 34	5 49 7 03	6 12 6 20	6 37 5 39	7 06 5 14	7 29 5 16												
24	7 28 5 44	7 00 6 15	6 22 6 39	5 41 7 04	5 14 7 27	5 10 7 42	5 26 7 33	5 50 7 02	6 13 6 18	6 37 5 38	7 07 5 13	7 30 5 17												
25	7 28 5 45	6 59 6 15	6 21 6 39	5 40 7 04	5 13 7 28	5 10 7 42	5 27 7 33	5 51 7 00	6 14 6 17	6 38 5 37	7 08 5 13	7 30 5 17												
26	7 27 5 46	6 58 6 16	6 19 6 40	5 38 7 05	5 13 7 29	5 11 7 42	5 28 7 32	5 51 6 59	6 14 6 15	6 39 5 36	7 09 5 13	7 31 5 18												
27	7 27 5 47	6 56 6 17	6 18 6 41	5 37 7 06	5 12 7 29	5 11 7 42	5 29 7 31	5 52 6 58	6 15 6 14	6 40 5 35	7 10 5 12	7 31 5 19												
28	7 26 5 48	6 55 6 18	6 17 6 42	5 36 7 07	5 12 7 30	5 11 7 42	5 29 7 31	5 53 6 56	6 16 6 12	6 41 5 34	7 11 5 12	7 31 5 19												
29	7 25 5 49	6 55 6 19	6 15 6 43	5 35 7 08	5 12 7 31	5 12 7 42	5 30 7 30	5 54 6 55	6 17 6 11	6 42 5 33	7 12 5 12	7 32 5 20												
30	7 25 5 50		6 14 6 43	5 34 7 08	5 11 7 31	5 12 7 42	5 31 7 29	5 54 6 54	6 17 6 09	6 43 5 31	7 13 5 12	7 32 5 21												
31	7 24 5 51		6 12 6 44		5 11 7 32		5 32 7 28	5 55 6 52		6 44 5 30		7 32 5 21												

Add one hour for Daylight Saving Time if and when in use.

SUNRISE AND SUNSET AT ELIZABETH CITY, NORTH CAROLINA NO. S1209-
EASTERN STANDARD TIME

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M. P.M.	Set A.M. P.M.																						
1	7 16 5 01	7 06 5 31	6 36 5 59	5 51 6 26	4 49 7 17	4 51 7 26	5 11 7 10	5 36 6 33	5 59 5 49	6 27 5 09	6 57 4 50													
2	7 16 5 01	7 05 5 32	6 34 6 00	5 50 6 27	5 11 6 53	4 48 7 17	4 51 7 26	5 12 6 32	6 00 5 47	6 28 5 08	6 58 4 50													
3	7 16 5 02	7 05 5 33	6 33 6 01	5 49 6 28	5 10 6 54	4 48 7 18	4 51 7 26	5 13 7 09	5 37 6 30	6 01 5 46	6 29 5 07	6 59 4 50												
4	7 17 5 03	7 04 5 34	6 32 6 02	5 47 6 29	5 09 6 55	4 48 7 18	4 52 7 26	5 13 7 08	5 38 6 29	6 02 5 44	6 30 5 06	7 00 4 50												
5	7 17 5 04	7 03 5 35	6 30 6 03	5 46 6 30	5 08 6 55	4 47 7 19	4 52 7 26	5 14 7 07	5 39 6 27	6 03 5 43	6 31 5 05	7 01 4 50												
6	7 17 5 05	7 02 5 36	6 29 6 04	5 44 6 31	5 07 6 56	4 47 7 19	4 53 7 25	5 15 7 06	5 40 6 26	6 04 5 42	6 32 5 04	7 02 4 50												
7	7 17 5 06	7 01 5 37	6 28 6 05	5 43 6 32	5 06 6 57	4 47 7 2																		

SUNRISE AND SUNSET AT FAYETTEVILLE, NORTH CAROLINA
EASTERN STANDARD TIME

NO. S1209-

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 24	5 15	7 15	5 44	6 45	6 11	6 03	6 37	5 25	7 01	5 03	7 24	5 05	7 33	5 25	7 19	5 48	6 43	6 10	6 00	6 36	5 22	7 05	5 04
2	7 24	5 16	7 14	5 45	6 44	6 12	6 02	6 37	5 24	7 01	5 02	7 25	5 05	7 33	5 25	7 18	5 49	6 41	6 11	5 59	6 37	5 21	7 06	5 04
3	7 24	5 16	7 13	5 46	6 43	6 13	6 00	6 38	5 23	7 02	5 02	7 25	5 06	7 33	5 26	7 17	5 49	6 40	6 11	5 57	6 38	5 20	7 07	5 04
4	7 24	5 17	7 12	5 47	6 42	6 14	5 59	6 39	5 22	7 03	5 02	7 26	5 06	7 33	5 27	7 16	5 50	6 39	6 12	5 56	6 39	5 19	7 08	5 04
5	7 24	5 18	7 12	5 48	6 40	6 14	5 57	6 40	5 21	7 04	5 02	7 26	5 07	7 33	5 28	7 15	5 51	6 37	6 13	5 54	6 40	5 18	7 08	5 04
6	7 24	5 19	7 11	5 49	6 39	6 15	5 56	6 41	5 20	7 05	5 02	7 27	5 07	7 33	5 28	7 14	5 52	6 36	6 14	5 53	6 41	5 17	7 09	5 04
7	7 24	5 20	7 10	5 50	6 38	6 16	5 55	6 41	5 19	7 06	5 01	7 27	5 08	7 33	5 29	7 13	5 52	6 34	6 15	5 52	6 42	5 16	7 10	5 04
8	7 24	5 21	7 09	5 51	6 36	6 17	5 53	6 42	5 18	7 06	5 01	7 28	5 08	7 32	5 30	7 12	5 53	6 33	6 15	5 50	6 43	5 15	7 11	5 04
9	7 24	5 21	7 08	5 52	6 35	6 18	5 52	6 43	5 17	7 07	5 01	7 28	5 09	7 32	5 31	7 11	5 54	6 32	6 16	5 49	6 44	5 15	7 12	5 04
10	7 24	5 22	7 07	5 53	6 34	6 19	5 51	6 44	5 16	7 08	5 01	7 29	5 09	7 32	5 31	7 10	5 54	6 30	6 17	5 48	6 45	5 14	7 12	5 04
11	7 24	5 23	7 06	5 54	6 32	6 20	5 49	6 45	5 15	7 09	5 01	7 29	5 10	7 31	5 32	7 09	5 55	6 29	6 18	5 46	6 46	5 13	7 13	5 04
12	7 24	5 24	7 05	5 55	6 31	6 20	5 48	6 45	5 15	7 10	5 01	7 30	5 11	7 31	5 33	7 08	5 56	6 27	6 19	5 45	6 47	5 12	7 14	5 04
13	7 24	5 25	7 04	5 56	6 30	6 21	5 47	6 46	5 14	7 10	5 01	7 30	5 11	7 31	5 34	7 07	5 57	6 26	6 19	5 44	6 48	5 12	7 15	5 05
14	7 24	5 26	7 03	5 57	6 28	6 22	5 45	6 47	5 13	7 11	5 01	7 31	5 12	7 30	5 34	7 05	5 57	6 24	6 20	5 42	6 49	5 11	7 15	5 05
15	7 23	5 27	7 02	5 58	6 27	6 23	5 44	6 48	5 12	7 12	5 01	7 31	5 13	7 30	5 35	7 04	5 58	6 23	6 21	5 41	6 50	5 10	7 16	5 05
16	7 23	5 28	7 01	5 59	6 25	6 24	5 43	6 49	5 11	7 13	5 01	7 31	5 13	7 29	5 36	7 03	5 59	6 21	6 22	5 40	6 51	5 10	7 17	5 06
17	7 23	5 29	7 00	6 00	6 24	6 25	5 41	6 49	5 11	7 13	5 01	7 32	5 14	7 29	5 37	7 02	6 00	6 20	6 23	5 39	6 52	5 09	7 17	5 06
18	7 22	5 30	6 59	6 01	6 23	6 25	5 40	6 50	5 10	7 14	5 01	7 32	5 14	7 28	5 37	7 01	6 00	6 19	6 24	5 37	6 53	5 08	7 18	5 06
19	7 22	5 31	6 58	6 02	6 21	6 26	5 39	6 51	5 09	7 15	5 01	7 32	5 15	7 28	5 38	7 00	6 01	6 17	6 25	5 36	6 54	5 08	7 18	5 07
20	7 22	5 32	6 56	6 03	6 20	6 27	5 38	6 52	5 09	7 16	5 02	7 32	5 16	7 27	5 39	6 58	6 02	6 16	6 25	5 35	6 55	5 07	7 19	5 07
21	7 21	5 33	6 55	6 04	6 18	6 28	5 37	6 53	5 08	7 16	5 02	7 33	5 17	7 27	5 40	6 57	6 02	6 14	6 26	5 34	6 56	5 07	7 20	5 08
22	7 21	5 34	6 54	6 05	6 17	6 29	5 35	6 53	5 07	7 17	5 02	7 33	5 17	7 26	5 40	6 56	6 03	6 13	6 27	5 32	6 57	5 07	7 20	5 08
23	7 20	5 35	6 53	6 06	6 16	6 29	5 34	6 54	5 07	7 18	5 02	7 33	5 18	7 26	5 41	6 55	6 04	6 11	6 28	5 31	6 57	5 06	7 21	5 09
24	7 20	5 36	6 52	6 06	6 14	6 30	5 33	6 55	5 06	7 19	5 02	7 33	5 19	7 25	5 42	6 53	6 05	6 10	6 29	5 30	6 58	5 06	7 21	5 09
25	7 19	5 37	6 50	6 07	6 13	6 31	5 32	6 56	5 08	7 19	5 03	7 33	5 19	7 24	5 43	6 52	6 05	6 09	6 30	5 29	6 55	5 05	7 21	5 10
26	7 19	5 38	6 49	6 08	6 11	6 32	5 31	6 57	5 05	7 20	5 03	7 33	5 20	7 23	5 43	6 51	6 06	6 07	6 31	5 28	7 00	5 05	7 22	5 10
27	7 18	5 39	6 48	6 09	6 10	6 33	5 29	6 57	5 05	7 21	5 03	7 33	5 21	7 23	5 44	6 49	6 07	6 06	6 32	5 27	7 01	5 05	7 22	5 11
28	7 17	5 40	6 47	6 10	6 09	6 33	5 28	6 58	5 04	7 21	5 04	7 33	5 22	7 22	5 45	6 48	6 08	6 04	6 33	5 26	7 02	5 05	7 23	5 12
29	7 17	5 41	6 46	6 11	6 07	6 34	5 27	6 59	5 04	7 22	5 04	7 33	5 22	7 21	5 46	6 47	6 08	6 03	6 33	5 25	7 03	5 04	7 23	5 12
30	7 16	5 42	6 45	6 12	6 06	6 35	5 26	7 00	5 03	7 23	5 05	7 44	5 23	7 20	5 46	6 45	6 09	6 01	6 34	5 24	7 04	5 04	7 23	5 13
31	7 15	5 43			6 04	6 36			5 03	7 23			5 24	7 19	5 47	6 44			6 35	5 23			7 23	5 14

Add one hour for Daylight Saving Time if and when in use.

SUNRISE AND SUNSET AT GREENSBORO, NORTH CAROLINA
EASTERN STANDARD TIME

NO. 121

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 31	5 16	7 21	5 46	6 50	6 14	6 07	6 41	5 27	7 07	5 04	7 31	5 06	7 41	5 27	7 25	5 51	6 48	6 15	6 04	6 42	5 24	7 12	5 06
2	7 31	5 17	7 20	5 47	6 49	6 15	6 05	6 42	5 26	7 08	5 04	7 32	5 07	7 41	5 27	7 24	5 52	6 46	6 15	6 02	6 43	5 23	7 13	5 05
3	7 31	5 18	7 19	5 49	6 48	6 16	6 04	6 43	5 25	7 09	5 04	7 32	5 07	7 41	5 28	7 23	5 53	6 45	6 16	6 01	6 44	5 22	7 14	5 05
4	7 31	5 19	7 18	5 50	6 46	6 17	6 02	6 44	5 24	7 09	5 03	7 33	5 08	7 40	5 29	7 22	5 53	6 44	6 17	6 00	6 45	5 21	7 15	5 05
5	7 31	5 19	7 18	5 51	6 45	6 18	6 01	6 45	5 23	7 10	5 03	7 34	5 08	7 40	5 30	7 21	5 54	6 42	6 18	5 58	6 46	5 20	7 15	5 05
6	7 31	5 20	7 17	5 52	6 44	6 19	5 59	6 46	5 22	7 11	5 03	7 34	5 09	7 40	5 31	7 20	5 55	6 41	6 19	5 57	6 47	5 19	7 16	5 05
7	7 31	5 21	7 16	5 53	6 42	6 20	5 58	6 47	5 21	7 12	5 03	7 35	5 09	7 40	5 31	7 19	5 56	6 39	6 20	5 55	6 48	5 18	7 17	5 05
8	7 31	5 22	7 15	5 54	6 41	6 21	5 57	6 47	5 20	7 13	5 02	7 35	5 10	7 40	5 32	7 18	5 57	6 38	6 20	5 54	6 49	5 18	7 18	5 05

SUNRISE AND SUNSET AT HICKORY, NORTH CAROLINA
EASTERN STANDARD TIME

NO. S1210-

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 36	5 23	7 26	5 53	6 56	6 20	6 13	6 47	5 34	7 12	5 11	7 36	5 13	7 45	5 33	7 30	5 57	6 53	6 20	6 10	6 47	5 31	7 17	5 12
2	7 36	5 24	7 25	5 54	6 55	6 21	6 11	6 48	5 33	7 13	5 11	7 37	5 13	7 45	5 34	7 29	5 58	6 52	6 21	6 08	6 48	5 30	7 18	5 12
3	7 36	5 24	7 24	5 55	6 53	6 22	6 10	6 49	5 32	7 14	5 10	7 37	5 14	7 45	5 35	7 28	5 59	6 51	6 22	6 07	6 49	5 29	7 19	5 12
4	7 36	5 25	7 24	5 56	6 52	6 23	6 08	6 49	5 31	7 14	5 10	7 38	5 14	7 45	5 35	7 27	5 59	6 49	6 23	6 05	6 50	5 28	7 19	5 12
5	7 36	5 26	7 23	5 57	6 51	6 24	6 07	6 50	5 30	7 15	5 10	7 38	5 15	7 45	5 36	7 26	6 00	6 48	6 23	6 04	6 51	5 27	7 20	5 12
6	7 36	5 27	7 22	5 58	6 49	6 25	6 05	6 51	5 29	7 16	5 10	7 39	5 15	7 45	5 37	7 25	6 01	6 46	6 24	6 03	6 52	5 26	7 21	5 12
7	7 36	5 28	7 21	5 59	6 48	6 26	6 04	6 52	5 28	7 17	5 09	7 39	5 16	7 45	5 38	7 24	6 02	6 45	6 25	6 01	6 53	5 25	7 22	5 12
8	7 36	5 29	7 20	6 00	6 47	6 27	6 03	6 53	5 27	7 18	5 09	7 40	5 16	7 44	5 38	7 23	6 02	6 43	6 26	6 00	6 54	5 24	7 23	5 12
9	7 36	5 30	7 19	6 01	6 45	6 28	6 01	6 54	5 26	7 19	5 09	7 40	5 17	7 44	5 39	7 22	6 03	6 42	6 27	5 58	6 55	5 23	7 24	5 12
10	7 36	5 31	7 18	6 02	6 44	6 28	6 00	6 54	5 25	7 19	5 09	7 41	5 18	7 44	5 40	7 21	6 04	6 40	6 28	5 57	6 56	5 22	7 24	5 12
11	7 36	5 31	7 17	6 03	6 42	6 29	5 59	6 55	5 24	7 20	5 09	7 41	5 18	7 43	5 41	7 20	6 05	6 39	6 28	5 56	6 57	5 22	7 25	5 12
12	7 36	5 32	7 16	6 04	6 41	6 30	5 57	6 56	5 23	7 21	5 09	7 42	5 19	7 43	5 42	7 19	6 06	6 38	6 29	5 54	6 58	5 21	7 26	5 13
13	7 35	5 33	7 15	6 05	6 40	6 31	5 56	6 57	5 22	7 22	5 09	7 42	5 19	7 43	5 42	7 18	6 06	6 36	6 30	5 53	6 59	5 20	7 27	5 13
14	7 35	5 34	7 14	6 06	6 38	6 32	5 55	6 58	5 21	7 23	5 09	7 43	5 20	7 42	5 43	7 17	6 07	6 35	6 31	5 52	7 00	5 19	7 27	5 13
15	7 35	5 35	7 13	6 07	6 37	6 33	5 53	6 59	5 21	7 23	5 09	7 43	5 21	7 42	5 44	7 16	6 08	6 33	6 32	5 50	7 01	5 19	7 28	5 13
16	7 35	5 36	7 12	6 08	6 35	6 34	5 52	6 59	5 20	7 24	5 09	7 43	5 21	7 41	5 45	7 14	6 09	6 32	6 33	5 49	7 02	5 18	7 29	5 14
17	7 34	5 37	7 11	6 09	6 34	6 34	5 51	7 00	5 19	7 25	5 09	7 44	5 22	7 41	5 46	7 13	6 09	6 30	6 34	5 48	7 03	5 17	7 29	5 14
18	7 34	5 38	7 10	6 10	6 33	6 35	5 49	7 01	5 18	7 26	5 09	7 44	5 23	7 40	5 46	7 12	6 10	6 29	6 34	5 47	7 04	5 17	7 30	5 14
19	7 34	5 39	7 08	6 11	6 31	6 36	5 48	7 02	5 18	7 27	5 09	7 44	5 23	7 40	5 47	7 11	6 11	6 27	6 35	5 45	7 05	5 16	7 30	5 15
20	7 33	5 40	7 07	6 12	6 30	6 37	5 47	7 03	5 17	7 27	5 09	7 44	5 24	7 39	5 48	7 09	6 12	6 26	6 36	5 44	7 06	5 16	7 31	5 15
21	7 33	5 41	7 06	6 13	6 28	6 38	5 46	7 04	5 16	7 28	5 10	7 45	5 25	7 39	5 49	7 08	6 12	6 24	6 37	5 43	7 07	5 15	7 32	5 16
22	7 32	5 42	7 05	6 14	6 27	6 39	5 44	7 04	5 16	7 29	5 10	7 45	5 25	7 38	5 49	7 07	6 13	6 23	6 38	5 42	7 08	5 15	7 32	5 16
23	7 32	5 43	7 04	6 15	6 25	6 40	5 43	7 05	5 15	7 30	5 10	7 45	5 26	7 37	5 50	7 05	6 14	6 21	6 39	5 40	7 09	5 14	7 33	5 17
24	7 31	5 44	7 02	6 16	6 24	6 40	5 42	7 06	5 14	7 30	5 10	7 45	5 27	7 37	5 51	7 04	6 15	6 20	6 40	5 39	7 10	5 14	7 33	5 17
25	7 31	5 45	7 01	6 17	6 23	6 41	5 41	7 07	5 14	7 31	5 11	7 45	5 28	7 36	5 52	7 03	6 15	6 18	6 41	5 38	7 11	5 14	7 33	5 18
26	7 30	5 46	7 00	6 18	6 21	6 42	5 39	7 08	5 13	7 32	5 11	7 45	5 28	7 35	5 53	7 02	6 16	6 17	6 42	5 37	7 12	5 13	7 34	5 18
27	7 30	5 48	6 59	6 19	6 20	6 43	5 38	7 09	5 13	7 33	5 11	7 45	5 29	7 34	5 53	7 00	6 17	6 16	6 43	5 36	7 13	5 13	7 34	5 19
28	7 29	5 49	6 57	6 20	6 18	6 44	5 37	7 09	5 12	7 33	5 12	7 46	5 30	7 33	5 54	6 59	6 18	6 14	6 44	5 35	7 14	5 13	7 34	5 20
29	7 28	5 50	6 57	6 20	6 17	6 45	5 36	7 10	5 12	7 34	5 12	7 46	5 31	7 33	5 55	6 57	6 19	6 13	6 44	5 34	7 15	5 13	7 35	5 20
30	7 28	5 51			6 15	6 45	5 35	7 11	5 12	7 35	5 12	7 45	5 31	7 32	5 56	6 56	6 19	6 11	6 45	5 33	7 16	5 12	7 35	5 21
31	7 27	5 52			6 14	6 46		5 11	7 35		5 32	7 31	5 56	6 55			6 46	5 32			7 35	5 22		

Add one hour for Daylight Saving Time if and when in use.

SUNRISE AND SUNSET AT NEW BERN, NORTH CAROLINA
EASTERN STANDARD TIME

NO. S1210-E

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 16	5 07	7 07	5 37	6 38	6 04	5 56	6 29	5 18	6 53	4 55	7 17	4 57	7 26	5 17	7 11	5 40	6 35	6 03	5 53	6 29	5 14	6 58	4 56
2	7 17	5 08	7 07	5 38	6 37	6 04	5 54	6 30	5 17	6 54	4 55	7 17	4 58	7 26	5 18	7 10	5 41	6 34	6 03	5 51	6 30	5 13	6 59	4 56
3	7 17	5 09	7 06	5 39	6 36	6 05	5 53	6 31	5 15	6 55	4 55	7 18	4 58	7 26	5 18	7 10	5 42	6 33	6 04	5 50	6 31	5 12	6 59	4 56
4	7 17	5 10	7 05	5 40	6 34	6 06	5 51	6 32	5 14	6 56	4 54	7 19	4 59	7 26	5 19	7 12	5 43	6 31	6 05	5 48	6 32	5 11	7 00	4 56
5	7 17	5 10	7 04	5 41	6 33	6 07	5 50	6 32	5 13	6 57	4 54	7 19	4 59	7 26	5 20	7 08	5 43	6 30	6 06	5 47	6 33	5 10	7 01	4 56
6	7 17	5 11	7 03	5 42	6 32	6 08	5 49	6 33	5 12	6 57	4 54	7 20	5 00	7 26	5 21	7 07	5 44	6 28	6 06	5 46	6 34	5 09	7 02	4 56
7	7 17	5 12	7 02	5 43	6 30	6 09	5 47	6 34	5 12	6 58	4 54	7 20	5 00	7 25	5 22	7 06	5 45	6 27	6 07	5 44	6 35	5 09	7 03	4 56
8	7 17	5 13	7 02	5 44	6 29	6 10	5 46	6 35	5 11	6 59	4 54	7 21	5 01	7 25	5 22	7 05	5 46	6 26	6 08	5 43	6 36	5 08	7 04	4 56
9	7 17																							

SUNRISE AND SUNSET AT RALEIGH, NORTH CAROLINA
EASTERN STANDARD TIME

NO. 12

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 26	5 12	7 16	5 42	6 46	6 10	6 02	6 37	5 23	7 02	5 00	7 26	5 02	7 35	5 22	7 20	5 47	6 43	6 10	5 59	6 37	5 20	7 07	5 01
2	7 26	5 13	7 15	5 43	6 44	6 11	6 01	6 38	5 22	7 03	5 00	7 26	5 03	7 35	5 23	7 19	5 47	6 42	6 11	5 58	6 38	5 19	7 08	5 01
3	7 26	5 14	7 14	5 44	6 43	6 12	5 59	6 38	5 21	7 04	4 59	7 27	5 03	7 35	5 24	7 18	5 48	6 40	6 11	5 56	6 39	5 18	7 08	5 01
4	7 26	5 15	7 13	5 45	6 42	6 13	5 58	6 39	5 20	7 04	4 59	7 28	5 04	7 35	5 25	7 17	5 49	6 39	6 12	5 55	6 40	5 17	7 09	5 01
5	7 26	5 15	7 13	5 46	6 40	6 14	5 56	6 40	5 19	7 05	4 59	7 28	5 04	7 35	5 26	7 16	5 50	6 37	6 13	5 54	6 41	5 16	7 10	5 01
6	7 26	5 16	7 12	5 47	6 39	6 15	5 55	6 41	5 18	7 06	4 59	7 29	5 05	7 35	5 26	7 15	5 51	6 36	6 14	5 52	6 42	5 15	7 11	5 01
7	7 26	5 17	7 11	5 48	6 38	6 15	5 54	6 42	5 17	7 07	4 59	7 29	5 05	7 35	5 27	7 14	5 51	6 34	6 15	5 51	6 43	5 14	7 12	5 01
8	7 26	5 18	7 10	5 49	6 36	6 16	5 52	6 43	5 16	7 08	4 58	7 30	5 06	7 34	5 28	7 13	5 52	6 33	6 16	5 49	6 44	5 13	7 13	5 01
9	7 26	5 19	7 09	5 50	6 35	6 17	5 51	6 43	5 15	7 09	4 58	7 30	5 06	7 34	5 29	7 12	5 53	6 32	6 16	5 48	6 45	5 12	7 14	5 01
10	7 26	5 20	7 08	5 51	6 33	6 18	5 49	6 44	5 14	7 09	4 58	7 31	5 07	7 34	5 29	7 11	5 54	6 30	6 17	5 47	6 46	5 12	7 14	5 01
11	7 26	5 21	7 07	5 52	6 32	6 19	5 48	6 45	5 13	7 10	4 58	7 31	5 07	7 33	5 30	7 10	5 54	6 29	6 18	5 45	6 47	5 11	7 15	5 02
12	7 26	5 22	7 06	5 54	6 31	6 20	5 47	6 46	5 12	7 11	4 58	7 32	5 08	7 33	5 31	7 09	5 55	6 27	6 19	5 44	6 48	5 10	7 16	5 02
13	7 25	5 23	7 05	5 55	6 29	6 21	5 45	6 47	5 11	7 12	4 58	7 32	5 09	7 33	5 32	7 07	5 56	6 26	6 20	5 42	6 49	5 09	7 17	5 02
14	7 25	5 24	7 04	5 56	6 28	6 22	5 44	6 48	5 11	7 13	4 58	7 33	5 09	7 32	5 33	7 06	5 57	6 24	6 21	5 41	6 50	5 09	7 17	5 02
15	7 25	5 25	7 03	5 57	6 26	6 22	5 43	6 48	5 10	7 13	4 58	7 33	5 10	7 32	5 33	7 05	5 57	6 23	6 22	5 40	6 51	5 08	7 18	5 03
16	7 25	5 26	7 02	5 58	6 25	6 23	5 41	6 49	5 09	7 14	4 58	7 33	5 11	7 31	5 34	7 04	5 58	6 21	6 22	5 39	6 52	5 07	7 19	5 03
17	7 24	5 27	7 00	5 59	6 24	6 24	5 40	6 50	5 08	7 15	4 58	7 34	5 11	7 31	5 35	7 03	5 59	6 20	6 23	5 37	6 53	5 07	7 19	5 03
18	7 24	5 28	6 59	6 00	6 22	6 25	5 39	6 51	5 08	7 16	4 58	7 34	5 12	7 30	5 36	7 02	6 00	6 18	6 24	5 36	6 54	5 06	7 20	5 04
19	7 24	5 29	6 58	6 00	6 21	6 26	5 37	6 52	5 07	7 17	4 59	7 34	5 13	7 30	5 37	7 00	6 00	6 17	6 25	5 35	6 55	5 06	7 20	5 04
20	7 23	5 30	6 57	6 01	6 19	6 27	5 36	6 53	5 06	7 17	4 59	7 34	5 13	7 29	5 37	6 59	6 01	6 15	6 26	5 33	6 56	5 05	7 21	5 04
21	7 23	5 31	6 56	6 02	6 18	6 28	5 35	6 53	5 06	7 18	4 59	7 35	5 14	7 28	5 38	6 58	6 02	6 14	6 27	5 32	6 57	5 05	7 22	5 05
22	7 22	5 32	6 55	6 03	6 16	6 28	5 34	6 54	5 05	7 19	4 59	7 35	5 15	7 28	5 39	6 56	6 03	6 12	6 28	5 31	6 58	5 04	7 22	5 05
23	7 22	5 33	6 53	6 04	6 15	6 29	5 32	6 55	5 04	7 20	4 59	7 35	5 16	7 27	5 40	6 55	6 04	6 11	6 29	5 30	6 59	5 04	7 22	5 06
24	7 21	5 34	6 52	6 05	6 13	6 30	5 31	6 56	5 04	7 20	5 00	7 35	5 16	7 26	5 40	6 54	6 04	6 09	6 30	5 29	7 00	5 03	7 23	5 07
25	7 21	5 35	6 51	6 06	6 12	6 31	5 30	6 57	5 03	7 21	5 00	7 35	5 17	7 26	5 41	6 53	6 05	6 08	6 31	5 27	7 01	5 03	7 23	5 07
26	7 20	5 36	6 50	6 07	6 11	6 32	5 29	6 58	5 03	7 22	5 00	7 35	5 18	7 25	5 42	6 51	6 06	6 07	6 31	5 26	7 02	5 03	7 24	5 08
27	7 19	5 37	6 48	6 08	6 09	6 33	5 28	6 58	5 02	7 23	5 01	7 35	5 19	7 24	5 43	6 50	6 07	6 05	6 32	5 25	7 03	5 02	7 24	5 08
28	7 19	5 38	6 47	6 09	6 08	6 33	5 26	6 59	5 02	7 23	5 01	7 35	5 19	7 23	5 44	6 49	6 07	6 04	6 33	5 24	7 04	5 02	7 24	5 09
29	7 18	5 39	6 47	6 10	6 06	6 34	5 25	7 00	5 01	7 24	5 01	7 35	5 20	7 23	5 44	6 47	6 08	6 02	6 34	5 23	7 05	5 02	7 25	5 10
30	7 17	5 40	6 05	6 35	5 24	7 01	5 01	7 25	5 02	7 35	5 21	7 22	5 45	6 46	6 09	6 01	6 35	5 22	7 06	5 02	7 25	5 11	7 25	5 10
31	7 17	5 41			6 03	6 36			5 00	7 25			5 22	7 21	5 46	6 44			6 36	5 21			7 25	5 11

Add one hour for Daylight Saving Time if and when in use.

SUNRISE AND SUNSET AT ROCKY MOUNT, NORTH CAROLINA
EASTERN STANDARD TIME

NO. S1211-

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 22	5 08	7 12	5 38	6 42	6 06	5 58	6 33	5 19	6 58	4 56	7 22	5 08	7 32	5 18	7 11	5 43	6 39	6 06	5 55	6 33	5 16	7 03	4 57
2	7 22	5 09	7 11	5 39	6 41	6 07	5 57	6 34	5 18	6 59	4 56	7 23	5 08	7 32	5 19	7 15	5 43	6 38	6 07	5 54	6 34	5 15	7 04	4 57
3	7 22	5 09	7 11	5 40	6 39	6 08	5 55	6 34	5 17	7 00	4 55	7 23	5 09	7 32	5 20	7 14	5 44	6 36	6 08	5 52	6 35	5 14	7 05	4 57
4	7 22	5 10	7 10	5 41	6 38	6 09	5 54	6 35	5 16	7 01	4 55	7 24	5 09	7 31	5 21	7 13	5 45	6 35	6 08	5 51	6 36	5 13	7 06	4 57
5	7 22	5 11	7 09	5 42	6 37	6 10	5 52	6 36	5 15	7 01	4 55	7 25	5 00	7 31	5 21	7 12	5 46	6 34	6 09	5 50	6 37	5 12	7 07	4 57
6	7 22	5 12	7 08	5 43	6 35	6 10	5 51	6 37	5 14	7 02	4 55	7 25	5 00	7 31	5 22	7 11	5 46	6 32	6 10	5 48	6 38	5 11	7 07	4 57
7	7 22	5 13	7 07	5 44	6 34	6 11	5 50	6 38	5 13	7 03	4 54	7 26	5 01	7 31	5 23	7 10	5 47	6 31	6 11	5 47	6 39	5 10	7 08	4 57
8	7 22	5 14	7 06	5 45	6 32	6 12	5 48	6 39	5 12	7 04	4 54	7 26	5 01	7 31	5 24	7 09	5 48	6 29	6 12	5 45	6 40	5 09	7 09	4 57
9																								

SUNRISE AND SUNSET AT WILMINGTON, NORTH CAROLINA
EASTERN STANDARD TIME

NO. 121

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 18	5 13	7 09	5 42	6 41	6 08	5 59	6 32	5 22	6 56	5 01	7 18	5 03	7 28	5 22	7 13	5 45	6 38	6 06	5 56	6 31	5 19	6 59	5 02
2	7 18	5 14	7 09	5 43	6 40	6 09	5 58	6 33	5 21	6 56	5 00	7 19	5 04	7 28	5 23	7 12	5 45	6 37	6 07	5 55	6 32	5 18	7 00	5 02
3	7 18	5 14	7 08	5 44	6 38	6 09	5 57	6 34	5 20	6 57	5 00	7 19	5 04	7 27	5 24	7 11	5 46	6 35	6 07	5 54	6 33	5 17	7 01	5 02
4	7 18	5 15	7 07	5 45	6 37	6 10	5 55	6 35	5 19	6 58	5 00	7 20	5 04	7 27	5 24	7 11	5 47	6 34	6 08	5 52	6 34	5 16	7 02	5 02
5	7 18	5 16	7 06	5 46	6 36	6 11	5 54	6 35	5 18	6 59	5 00	7 21	5 05	7 27	5 25	7 10	5 48	6 33	6 09	5 51	6 35	5 15	7 03	5 02
6	7 19	5 17	7 06	5 47	6 35	6 12	5 53	6 36	5 17	7 00	5 00	7 21	5 05	7 27	5 26	7 09	5 48	6 31	6 10	5 49	6 36	5 14	7 04	5 02
7	7 19	5 18	7 05	5 47	6 33	6 13	5 51	6 37	5 16	7 00	4 59	7 22	5 06	7 27	5 27	7 08	5 49	6 30	6 10	5 48	6 37	5 13	7 04	5 02
8	7 19	5 18	7 04	5 48	6 32	6 14	5 50	6 38	5 16	7 01	4 59	7 22	5 06	7 27	5 27	7 07	5 50	6 29	6 11	5 47	6 38	5 13	7 05	5 02
9	7 19	5 19	7 03	5 49	6 31	6 14	5 49	6 38	5 15	7 02	4 59	7 23	5 07	7 26	5 28	7 06	5 50	6 27	6 12	5 45	6 39	5 12	7 06	5 02
10	7 19	5 20	7 02	5 50	6 30	6 15	5 47	6 39	5 14	7 03	4 59	7 23	5 08	7 26	5 29	7 05	5 51	6 26	6 13	5 44	6 40	5 11	7 07	5 02
11	7 18	5 21	7 01	5 51	6 28	6 16	5 46	6 40	5 13	7 03	4 59	7 23	5 08	7 26	5 30	7 04	5 52	6 24	6 14	5 43	6 41	5 10	7 07	5 02
12	7 18	5 22	7 00	5 52	6 27	6 17	5 45	6 41	5 12	7 04	4 59	7 24	5 09	7 25	5 30	7 02	5 52	6 23	6 14	5 42	6 42	5 10	7 08	5 02
13	7 18	5 23	6 59	5 53	6 25	6 18	5 43	6 42	5 11	7 05	4 59	7 24	5 09	7 25	5 31	7 01	5 53	6 22	6 15	5 40	6 43	5 09	7 09	5 03
14	7 18	5 24	6 58	5 54	6 24	6 18	5 42	6 42	5 11	7 06	4 59	7 25	5 10	7 25	5 32	7 00	5 54	6 20	6 16	5 39	6 44	5 08	7 10	5 03
15	7 18	5 25	6 57	5 55	6 23	6 19	5 41	6 43	5 10	7 06	4 59	7 25	5 11	7 24	5 32	6 59	5 55	6 19	6 17	5 38	6 44	5 08	7 10	5 03
16	7 17	5 26	6 56	5 56	6 21	6 20	5 40	6 44	5 09	7 07	4 59	7 25	5 11	7 24	5 33	6 58	5 55	6 17	6 18	5 37	6 45	5 07	7 11	5 04
17	7 17	5 27	6 55	5 57	6 20	6 21	5 38	6 45	5 08	7 08	4 59	7 26	5 12	7 23	5 34	6 57	5 56	6 16	6 18	5 35	6 46	5 07	7 12	5 04
18	7 17	5 28	6 54	5 58	6 19	6 22	5 37	6 45	5 08	7 09	4 59	7 26	5 12	7 23	5 35	6 56	5 57	6 14	6 19	5 34	6 47	5 06	7 12	5 04
19	7 17	5 29	6 53	5 59	6 17	6 22	5 36	6 46	5 07	7 09	5 00	7 26	5 13	7 22	5 35	6 55	5 57	6 13	6 20	5 33	6 48	5 06	7 13	5 05
20	7 16	5 30	6 50	6 00	6 16	6 23	5 35	6 47	5 06	7 10	5 00	7 27	5 14	7 22	5 36	6 53	5 58	6 12	6 21	5 32	6 49	5 05	7 13	5 05
21	7 16	5 31	6 51	6 01	6 14	6 24	5 34	6 48	5 06	7 11	5 00	7 27	5 14	7 21	5 37	6 52	5 59	6 10	6 22	5 31	6 50	5 05	7 14	5 06
22	7 15	5 32	6 49	6 02	6 13	6 25	5 32	6 49	5 05	7 12	5 00	7 27	5 15	7 21	5 38	6 51	5 59	6 09	6 23	5 29	6 51	5 04	7 14	5 06
23	7 15	5 33	6 48	6 02	6 12	6 25	5 31	6 49	5 05	7 12	5 00	7 27	5 16	7 20	5 38	6 50	6 00	6 07	6 23	5 28	6 52	5 04	7 15	5 07
24	7 14	5 34	6 47	6 03	6 10	6 26	5 30	6 50	5 04	7 13	5 01	7 27	5 16	7 19	5 39	6 48	6 01	6 06	6 24	5 27	6 53	5 03	7 15	5 07
25	7 14	5 35	6 46	6 04	6 09	6 27	5 29	6 51	5 04	7 14	5 01	7 27	5 17	7 19	5 40	6 47	6 02	6 05	6 25	5 26	6 54	5 03	7 16	5 08
26	7 13	5 36	6 45	6 05	6 08	6 28	5 28	6 52	5 03	7 14	5 01	7 27	5 18	7 18	5 40	6 46	6 02	6 03	6 26	5 25	6 55	5 03	7 16	5 09
27	7 13	5 37	6 43	6 06	6 06	6 29	5 27	6 52	5 03	7 15	5 02	7 28	5 19	7 17	5 41	6 45	6 03	6 02	6 27	5 24	6 56	5 03	7 16	5 09
28	7 12	5 38	6 42	6 07	6 05	6 29	5 26	6 53	5 02	7 16	5 02	7 28	5 19	7 16	5 42	6 43	6 04	6 00	6 28	5 23	6 57	5 02	7 17	5 10
29	7 12	5 39	6 42	6 08	6 03	6 30	5 24	6 54	5 02	7 16	5 02	7 28	5 20	7 16	5 43	6 42	6 04	5 59	6 29	5 22	6 58	5 02	7 17	5 10
30	7 11	5 40	6 02	6 31	5 23	6 55	5 01	7 17	5 03	7 28	5 21	7 15	5 43	6 41	6 05	6 05	5 58	6 30	5 21	6 58	5 02	7 17	5 11	
31	7 10	5 41			6 01	6 32			5 01	7 18			5 21	7 14	5 44	6 39			6 30	5 20			7 18	5 12

Add one hour for Daylight Saving Time if and when in use.

SUNRISE AND SUNSET AT WINSTON-SALEM, NORTH CAROLINA
EASTERN STANDARD TIME

NO. 121:

DAY	JAN.		FEB.		MAR.		APR.		MAY		JUNE		JULY		AUG.		SEPT.		OCT.		NOV.		DEC.	
	Rise A.M.	Set P.M.																						
1	7 32	5 17	7 22	5 47	6 52	6 16	6 08	6 43	5 28	7 08	5 05	7 32	5 07	7 42	5 28	7 26	5 52	6 49	6 16	6 05	6 43	5 25	7 13	5 07
2	7 32	5 18	7 21	5 49	6 50	6 17	6 06	6 43	5 27	7 09	5 05	7 33	5 08	7 42	5 28	7 25	5 53	6 48	6 17	6 04	6 44	5 24	7 14	5 06
3	7 32	5 19	7 21	5 50	6 49	6 17	6 05	6 44	5 26	7 10	5 05	7 34	5 08	7 42	5 29	7 24	5 54	6 46	6 17	6 02	6 45	5 23	7 15	5 06
4	7 32	5 20	7 20	5 51	6 48	6 18	6 03	6 45	5 25	7 11	5 04	7 34	5 09	7 42	5 30	7 23	5 55	6 45	6 18	6 01	6 46	5 22	7 16	5 06
5	7 32	5 20	7 19	5 52	6 46	6 19	6 02	6 46	5 24	7 11	5 04	7 35	5 09	7 41	5 31	7 22	5 55	6 43	6 19	6 07	6 47	5 21	7 17	5 06
6	7 33	5 21	7 18	5 53	6 45	6 20	6 01	6 47	5 23	7 12	5 04	7 35	5 10	7 41	5 32	7 21	5 56	6 42	6 20	5 58	6 48	5 20	7 18	5 06
7	7 33	5 22	7 17	5 54	6 44	6 21	5 59	6 48	5 22	7 13	5 04	7 36	5 10	7 41	5 32	7 20	5 57	6 40	6 21	5 56	6 49	5 20	7 18	5 06
8	7 32	5 23	7 16	5 55	6 42	6 22	5 58	6 49	5 21	7 14	5 03	7 36	5 11	7 41	5 33	7 19	5 58	6 39	6 22	5 55	6 50	5 19	7 19	5 06
9	7																							

APPENDIX A.3

STATISTICAL ANALYSIS ON CROSSING TIMES

APPENDIX A.3

Pitt County

Date	Crossing Time	Crossing Temperature	Delta t	Delta t Ratio	Weather Index
09-Feb-96	35104	0.513627	18.4696	0.233395	0.324541
10-Feb-96	35105	0.348751	4.6909	0.069179	0.096099
11-Feb-96	35106	0.308137	7.8667	0.029236	0.040572
12-Feb-96	35107	0.351228	5.3538	0.073022	0.101235
13-Feb-96	35108	0.356748	2.2444	0.079248	0.109759
14-Feb-96	35109	0.3336	7	0.056806	0.078598
15-Feb-96	35110	0.378107	8.1409	0.102042	0.141052
15-May-96	35200	0.324659	19.2857	0.125886	0.161969
16-May-96	35201	0.437755	19.7	0.239502	0.307932
17-May-96	35202	0.281505	20.5	0.08375	0.107603
18-May-96	35203	0.259369	24.1313	0.062101	0.079732
19-May-96	35204	0.2673	26.0636	0.070495	0.090447
20-May-96	35205	0.272313	27.5471	0.075948	0.097378
21-May-96	35206	0.278032	28.7333	0.082095	0.105188
22-May-96	35207	0.307546	29.6	0.112025	0.143441
23-May-96	35208	0.282662	24.5	0.087523	0.111993
24-May-96	35209	0.278032	26.3667	0.083264	0.106474
25-May-96	35210	0.286239	28.6091	0.09183	0.117351
26-May-96	35211	0.299362	27.0786	0.105288	0.134465

SITE ID = 1
RECORDING DAYS= 21

Weather Index	Crossing Time		Delta t		Delta t Ratio		Number of Days
	Mean	STD	Mean	STD	Mean	STD	
ALL	0.3245	0.0644	0.0980	0.0532	0.1293	0.0712	19
100-50	0.2996	0.0348	0.0760	0.0195	0.0996	0.0242	12
50 - 0	0.3136	0.0272	0.0901	0.0346	0.1175	0.0420	3
0 - -2	0.3717	0.0694	0.1489	0.0784	0.1945	0.0983	3
500	0.5136	0.0000	0.2334	0.0000	0.3245	0.0000	1

APPENDIX A.3

Carteret County

Date		Crossing Time	Crossing Temperature	Delta t	Delta t Ratio	Weather Index
17-Feb-96	35112	0.3968	2.0381	0.1214	0.1670	500
18-Feb-96	35113	0.3783	2.8094	0.1036	0.1424	500
19-Feb-96	35114	0.3543	3.7550	0.0804	0.1104	500
20-Feb-96	35115	0.2123	7.5000	-0.0608	-0.0835	500
21-Feb-96	35116	0.0446	10.8286	-0.2277	-0.3121	500
22-Feb-96	35117	0.3390	10.3833	0.0675	0.0924	500
23-Feb-96	35118	0.3069	11.8875	0.0362	0.0495	500
24-Feb-96	35119	0.3322	14.4000	0.0623	0.0852	500
25-Feb-96	35120	0.3787	9.4722	0.1096	0.1496	500
26-Feb-96	35121	0.3121	11.7625	0.0439	0.0598	500
27-Feb-96	35122	0.3558	13.4111	0.0884	0.1205	500
28-Feb-96	35123	0.3512	14.5000	0.0846	0.1152	500
04-Apr-96	35159	0.3559	15.9250	0.1231	0.1630	100
05-Apr-96	35160	0.3403	17.5500	0.1084	0.1434	100
06-Apr-96	35161	0.3421	16.9588	0.1111	0.1470	-1
07-Apr-96	35162	0.3426	12.2609	0.1125	0.1487	-1
08-Apr-96	35163	0.2989	11.1030	0.0698	0.0922	75
09-Apr-96	35164	0.3056	13.1833	0.0773	0.1021	0
10-Apr-96	35165	0.3048	9.1000	0.0775	0.1022	100
11-Apr-96	35166	0.2967	11.0815	0.0703	0.0926	500

SITE ID = 2
RECORDING DAYS= 22

Weather Index	Crossing Time		Delta t		Delta t Ratio		Number of Days
	Mean	STD	Mean	STD	Mean	STD	
ALL	0.3175	0.0755	0.0630	0.0797	0.0844	0.1084	20
100-50	0.3250	0.0276	0.0947	0.0252	0.1252	0.0336	4
50 - 0	0.3056	0.0000	0.0773	0.0000	0.1021	0.0000	1
0 - -2	0.3423	0.0003	0.1118	0.0010	0.1478	0.0012	2
500	0.3122	0.0931	0.0446	0.0937	0.0607	0.1282	13

APPENDIX A.3

New Hanover County

Date	Crossing Time	Crossing Temperature	Delta t	Delta t Ratio	Weather Index
24-Aug-95	34935	0.300613	27.9	0.081227	0.106443
25-Aug-95	34936	0.310124	30.3043	0.090252	0.118402
27-Aug-95	34938	0.388881	27.8737	0.168001	0.220906
28-Aug-95	34939	0.361625	27.6429	0.140248	0.18463
29-Aug-95	34940	0.32353	26.06	0.101655	0.133981
30-Aug-95	34941	0.338411	27.4943	0.116038	0.153118
15-Nov-95	35018	0.400304	9.2686	0.137503	0.199203
16-Nov-95	35019	0.400486	9.1	0.136991	0.198584
17-Nov-95	35020	0.399276	8.5636	0.135109	0.195975
18-Nov-95	35021	0.386019	9	0.121169	0.175855
19-Nov-95	35022	0.387407	10.86	0.121887	0.176992
20-Nov-95	35023	0.396435	10.8	0.130243	0.189225
21-Nov-95	35024	0.364193	13.0048	0.09733	0.141473
22-Nov-95	35025	0.412639	9.7278	0.145104	0.211011
23-Nov-95	35026	0.390185	8.1	0.121979	0.177457
24-Nov-95	35027	0.357249	12.0381	0.088383	0.128633
25-Nov-95	35028	0.488458	11.4366	0.218933	0.318748
01-Feb-96	35096	0.42391	8.7609	0.142417	0.199741
04-Feb-96	35099	0.519285	2.7882	0.23932	0.334648
05-Feb-96	35100	0.430727	-0.2737	0.151306	0.21137
06-Feb-96	35101	0.419037	0.4577	0.140182	0.195641
23-Apr-96	35178	0.299287	24.6522	0.086209	0.113183
24-Apr-96	35179	0.335079	22	0.122788	0.161092
25-Apr-96	35180	0.313343	20.5414	0.101827	0.133495
26-Apr-96	35181	0.292467	23.7588	0.081727	0.107067
27-Apr-96	35182	0.29657	21.5391	0.086582	0.113347
28-Apr-96	35183	0.303889	22.6	0.094653	0.123825
29-Apr-96	35184	0.322951	25.0875	0.114444	0.149607
30-Apr-96	35185	0.325556	25.6	0.117778	0.153855

SITE ID = 3

RECORDING DAYS= 37

Weather Index	Crossing Time				Delta t		Delta t Ratio		Number of Days
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	
ALL	0.3686	0.0576	0.1252	0.0370	0.1734	0.0551	29		
100-50	0.3565	0.0476	0.1145	0.0225	0.1585	0.0365	18		
50 - 0	0.3918	0.0894	0.1431	0.0589	0.1981	0.0856	5		
0 - -2	0.3753	0.0193	0.1541	0.0196	0.2028	0.0257	2		
500	0.3904	0.0705	0.1368	0.0568	0.1947	0.0851	4		

APPENDIX A.3

Durham County

Date		Crossing Time	Crossing Temperature	Delta t	Delta t Ratio	Weather Index
12-Aug-95	34923	0.310543	30.1818	0.101608	0.131794	100
13-Aug-95	34924	0.31441	33.5917	0.104931	0.136239	100
14-Aug-95	34925	0.324789	34.9044	0.114789	0.149186	100
15-Aug-95	34926	0.326466	35.2037	0.115911	0.150798	100
16-Aug-95	34927	0.327778	34.12	0.11669	0.15197	100
17-Aug-95	34928	0.321165	34.3783	0.109534	0.142799	100
18-Aug-95	34929	0.326466	34.5074	0.114302	0.149175	100
31-Oct-95	35003	0.453482	17.6545	0.202382	0.291343	30
01-Nov-95	35004	0.429097	17.8625	0.177326	0.255537	30
02-Nov-95	35005	0.430213	18.9429	0.17776	0.256423	-1
03-Nov-95	35006	0.348368	19.3	0.095243	0.137528	-1
04-Nov-95	35007	0.43354	17.3588	0.179732	0.259779	100
05-Nov-95	35008	0.423021	13.6083	0.168507	0.243784	100
06-Nov-95	35009	0.403267	12.873	0.14807	0.214414	100
24-Jan-96	35088	0.095775	7.05	-0.18781	-0.26732	50
25-Jan-96	35089	0.401331	6.4	0.118113	0.167939	100
26-Jan-96	35090	0.424997	4.8947	0.142173	0.201939	100
28-Jan-96	35092	0.398165	6.5706	0.116174	0.16467	100
29-Jan-96	35093	0.5489	6.4	0.267361	0.378571	10
30-Jan-96	35094	0.444734	6.3	0.163669	0.231508	70

SITE ID = 4
RECORDING DAYS: 24

Weather Index	Crossing Time		Delta t		Delta t Ratio		Number of Days
	Mean	STD	Mean	STD	Mean	STD	
ALL	0.374325	0.090714	0.127323	0.085625	0.177404	0.123423	20
100-50	0.370048	0.051863	0.129586	0.025722	0.178285	0.043192	14
50 - 0	0.381814	0.197575	0.114814	0.205288	0.164533	0.292501	4
0 - -2	0.389291	0.057873	0.136501	0.058348	0.196975	0.084071	2
500	0	0	0	0	0	0	0

APPENDIX A.3

Polk County

Date	Crossing Time	Crossing Temperature	Delta t	Delta t Ratio	Weather Index
08-Feb-96	35103	0.332905	4.8	0.065417	0.092732
09-Feb-96	35104	0.028738	8.9	-0.2381	-0.33718
10-Feb-96	35105	0.368651	6.1211	0.102459	0.144946
11-Feb-96	35106	0.331979	10.1556	0.066458	0.093923
12-Feb-96	35107	0.384326	6.8545	0.119488	0.168699
13-Feb-96	35108	0.367554	3.2105	0.103422	0.145872
14-Feb-96	35109	0.366458	6.7632	0.103032	0.145174
02-Apr-96	35157	0.322294	8.0182	0.102514	0.138653
03-Apr-96	35158	0.32987	10.3273	0.11105	0.150084
04-Apr-96	35159	0.327147	16.4375	0.109288	0.14759
05-Apr-96	35160	0.338618	17.3905	0.121708	0.164239
06-Apr-96	35161	0.518317	15.0727	0.302356	0.407703
07-Apr-96	35162	0.287183	10.8615	0.072171	0.097243
08-Apr-96	35163	0.327029	13.8045	0.112955	0.152078
09-Apr-96	35164	0.287256	9.8409	0.074108	0.0997
10-Apr-96	35165	0.284178	8.8375	0.071956	0.096731

SITE ID = 5
RECORDING DAYS= 18

Weather Index	Crossing Time		Delta t		Delta t Ratio		Number of Days
	Mean	STD	Mean	STD	Mean	STD	
ALL	0.3252	0.0962	0.0875	0.1028	0.1193	0.1424	16
100-50	0.3189	0.1147	0.0843	0.1248	0.1139	0.1727	11
50 - 0	0.3421	0.0213	0.0938	0.0251	0.1300	0.0325	3
0 - -2	0.3843	0.0000	0.1195	0.0000	0.1687	0.0000	2
500	0.2842	0.0000	0.0720	0.0000	0.0967	0.0000	1

APPENDIX A.3

Wilkes County

Date	Crossing Time	Crossing Temperature	Delta t	Delta t Ratio	Weather Index
22-Aug-95	34933	0.338345	28.9	0.130822	0.172781
23-Aug-95	34934	0.344755	28.8538	0.136677	0.180727
24-Aug-95	34935	0.380508	28.7071	0.171885	0.227554
25-Aug-95	34936	0.333816	28.1348	0.124649	0.165217
28-Aug-95	34939	0.327928	24.15	0.117118	0.155806
29-Aug-95	34940	0.333715	25.3778	0.122361	0.162985
30-Aug-95	34941	0.335628	27.2609	0.123729	0.165016
01-Nov-95	35004	0.358524	13.4187	0.112344	0.163522
02-Nov-95	35005	0.357823	16.2692	0.110948	0.161659
03-Nov-95	35006	0.336761	16.7	0.089191	0.130092
04-Nov-95	35007	0.384072	10.1069	0.135808	0.198284
05-Nov-95	35008	0.395188	6.2684	0.146218	0.213692
06-Nov-95	35009	0.379239	5.3727	0.129563	0.189531
29-Jan-96	35093	0.47066	2.22	0.194514	0.278222
30-Jan-96	35094	0.38316	2.4	0.1075	0.153599
31-Jan-96	35095	0.356076	4.32	0.080914	0.115489
01-Feb-96	35096	0.542188	3.4833	0.267546	0.381459
04-Feb-96	35099	0.418766	-4.7	0.145791	0.207201
05-Feb-96	35100	0.406583	-8.2378	0.134199	0.190522
06-Feb-96	35101	0.383993	-5.628	0.112222	0.159154
23-Apr-96	35178	0.33485	21.9111	0.132697	0.175965
24-Apr-96	35179	0.337264	15.6514	0.135956	0.180143
25-Apr-96	35180	0.318468	15.9346	0.117982	0.156205
26-Apr-96	35181	0.496887	18.5667	0.297211	0.393192
27-Apr-96	35182	0.317888	16.2207	0.119022	0.157336
28-Apr-96	35183	0.317169	16.6241	0.11909	0.157302
29-Apr-96	35184	0.328957	21.6	0.131666	0.173776
30-Apr-96	35185	0.434702	19.1	0.238174	0.314105

SITE ID = 7
RECORDING DAYS= 36

Weather Index	Crossing Time		Delta t		Delta t Ratio		Number of Days
	Mean	STD	Mean	STD	Mean	STD	
ALL	0.3734	0.0564	0.1424	0.0499	0.1957	0.0674	28
100-50	0.3594	0.0345	0.1322	0.0149	0.1814	0.0226	15
50 - 0	0.3710	0.0846	0.1473	0.0595	0.2023	0.0881	6
0 - -2	0.3942	0.0606	0.1540	0.0907	0.2114	0.1142	6
500	0.4707	0.0000	0.1945	0.0000	0.2782	0.0000	1

APPENDIX A.4

WEATHER RECORDS

CARTERET

DATE	DATE	WEATHER INDEX		
		MORNING	NOON	AFTERNOON
04-Apr-96	35159	100	100	100
05-Apr-96	35160	100	50	25
06-Apr-96	35161	-1	-1	-1
07-Apr-96	35162	-1	0	50
08-Apr-96	35163	75	25	0
09-Apr-96	35164	0	25	75
10-Apr-96	35165	100	100	100

DURHAM

DATE	DATE	WEATHER INDEX		
		MORNING	NOON	AFTERNOON
11-Aug-95	34922	100	100	100
12-Aug-95	34923	100	100	100
13-Aug-95	34924	100	100	100
14-Aug-95	34925	100	100	100
15-Aug-95	34926	100	100	100
16-Aug-95	34927	100	100	100
17-Aug-95	34928	100	100	100
18-Aug-95	34929	100	100	100
30-Oct-95	35002	500	50	100
31-Oct-95	35003	30	75	75
01-Nov-95	35004	30	40	-1
02-Nov-95	35005	-1	-1	-1
03-Nov-95	35006	-1	90	100
04-Nov-95	35007	100	100	100
05-Nov-95	35008	100	80	100
06-Nov-95	35009	100	100	100
23-Jan-96	35087	500	500	75
24-Jan-96	35088	50	30	70
25-Jan-96	35089	100	100	100
26-Jan-96	35090	100	80	-1
27-Jan-96	35091	50	50	50
28-Jan-96	35092	100	100	100
29-Jan-96	35093	10	-1	-1
30-Jan-96	35094	70	50	500
25-Mar-96	35149	500	75	80
26-Mar-96	35150	10	60	80
27-Mar-96	35151	10	20	20
28-Mar-96	35152	-1	-1	-1
29-Mar-96	35153	10	50	90
30-Mar-96	35154	10	80	80
31-Mar-96	35155	-1	0	0
07-May-96	35192	0	0	20
08-May-96	35193	0	0	0
09-May-96	35194	90	500	500
10-May-96	35195	500	500	500
11-May-96	35196	500	500	500
12-May-96	35197	500	500	500
13-May-96	35198	500	500	500

NEW HANOVER

DATE	DATE	WEATHER INDEX		
		MORNING	NOON	AFTERNOON
22-Aug-95	34934	500	100	100
23-Aug-95	34934	-1	-1	0
24-Aug-95	34935	100	70	90
25-Aug-95	34936	100	65	85
26-Aug-95	34937	-1	-1	-1
27-Aug-95	34938	-1	-1	-1
28-Aug-95	34939	-1	-1	-1
29-Aug-95	34940	100	100	100
30-Aug-95	34941	100	100	500
14-Nov-95	35017	500	100	-1
15-Nov-95	35018	40	50	100
16-Nov-95	35019	100	100	100
17-Nov-95	35020	100	100	100
18-Nov-95	35021	90	100	100
19-Nov-95	35022	100	100	100
20-Nov-95	35023	95	50	20
21-Nov-95	35024	100	70	70
22-Nov-95	35025	100	100	100
01-Feb-96	35096	0	0	0
02-Feb-96	35097	0	-1	-2
03-Feb-96	35098	-2	-2	-2
04-Feb-96	35099	50	-2	100
05-Feb-96	35100	100	80	50
06-Feb-96	35101	100	100	100
22-Apr-96	35177	0	75	100
23-Apr-96	35178	90	90	100
24-Apr-96	35179	85	80	80
25-Apr-96	35180	100	100	100
26-Apr-96	35181	50	25	0
27-Apr-96	35182	95	95	95
28-Apr-96	35183	100	100	90
29-Apr-96	35184	15	0	0

POLK

DATE	DATE	WEATHER INDEX		
		MORNING	NOON	AFTERNOON
07-Feb-96	35102	500	100	50
08-Feb-96	35103	30	65	45
09-Feb-96	35104	100	100	100
10-Feb-96	35105	100	100	100
11-Feb-96	35106	100	100	100
12-Feb-96	35107	-2	25	75
13-Feb-96	35108	100	100	100
14-Feb-96	35109	50	100	100
01-Apr-96	35156	500	20	100
02-Apr-96	35157	100	100	100
03-Apr-96	35158	100	100	100
04-Apr-96	35159	100	100	100
05-Apr-96	35160	75	75	100
06-Apr-96	35161	60	40	-1
07-Apr-96	35162	100	100	100
08-Apr-96	35163	50	50	-1
09-Apr-96	35164	100	100	100

PITT

DATE	DATE	WEATHER INDEX		
		MORNING	NOON	AFTERNOON
09-Feb-96	35104	500	80	80
10-Feb-96	35105	100	100	100
11-Feb-96	35106	100	80	100
12-Feb-96	35107	100	70	50
13-Feb-96	35108	100	100	90
14-Feb-96	35109	0	0	50
15-Feb-96	35110	-1	50	100
16-Feb-96	35111	-1	-2	-2
13-May-96	35198	500	500	500
14-May-96	35199	500	500	500
15-May-96	35200	500	500	500
16-May-96	35201	500	500	500
17-May-96	35202	500	500	500
18-May-96	35203	500	500	500
19-May-96	35204	500	500	500
20-May-96	35205	500	500	500

WILKES

DATE	DATE	WEATHER INDEX		
		MORNING	NOON	AFTERNOON
21-Aug-95	34932	500	100	100
22-Aug-95	34933	100	100	100
23-Aug-95	34934	80	80	60
24-Aug-95	34935	90	80	60
25-Aug-95	34936	80	100	100
26-Aug-95	34937	-1	-1	-1
27-Aug-95	34938	-1	-1	-1
28-Aug-95	34939	40	65	90
29-Aug-95	34940	30	100	100
30-Aug-95	34941	100	100	500
30-Oct-95	35002	500	60	40
31-Oct-95	35003	-1	-1	-1
01-Nov-95	35004	40	75	5
02-Nov-95	35005	-1	-1	-1
03-Nov-95	35006	-1	-1	-1
04-Nov-95	35007	100	100	100
05-Nov-95	35008	100	100	100
06-Nov-95	35009	100	100	100
29-Jan-96	35093	500	15	-1
30-Jan-96	35094	-1	5	5
31-Jan-96	35095	-1	40	80
01-Feb-96	35096	10	10	5
02-Feb-96	35097	-2	-2	-2
03-Feb-96	35098	-2	-2	-1
04-Feb-96	35099	100	100	100
05-Feb-96	35100	100	50	15
06-Feb-96	35101	100	100	100
22-Apr-96	35177	500	10	10
23-Apr-96	35178	10	50	10
24-Apr-96	35179	100	100	100
25-Apr-96	35180	100	100	100
26-Apr-96	35181	-1	-1	50
27-Apr-96	35182	100	100	100
28-Apr-96	35183	100	100	100
29-Apr-96	35184	10	50	-1
30-Apr-96	35185	-1	50	500

APPENDIX A.5

TEMPERATURE PREDICTION PROGRAMS

```

C
C*****Temperature Prediction based on the Surface
C      Temperature Records
C
C*****CHARACTER*70 JUNK1,JUNK2
CHARACTER*12 INA,ON
CHARACTER*9 DATEC(2000)
CHARACTER*10 TIMEC(2000)
CHARACTER*9 DATE
CHARACTER*10 TIME
COMMON DY(100),TP(100)
DIMENSION DYT(2000,2),T(2000,4),X(10),T1(10,2000),
& T2(10,2000),TT(10,2000),AA(2000),BB(2000)
WRITE(*,*) 'INPUT DATE-TEMPERATURE FILE NAME:'
READ(*,'(A)')INA
WRITE(*,*) 'OUTPUT TEMPERATURE FILE NAME:'
READ(*,'(A)')ON
OPEN(17,FILE=INA,STATUS='OLD')
OPEN(16,FILE=ON)

C      INPUT LAYERS NUMBER AND THICKNESS
C
READ(17,10) JUNK1
WRITE(16,*) JUNK1
C
READ(17,*) LAYER
WRITE(16,11) LAYER
11 FORMAT(//1X,'NUMBER OF DEPTH INTERESTED: LAYER=',
* I3,/1X,'DEPTH')
READ(17,*) (X(I),I=1,LAYER)
WRITE(16,*) (X(I),I=1,LAYER)
READ(17,*) CROSS
WRITE(16,21) CROSS
21 FORMAT(//1X,'CROSSING TIME =',F8.4)
CROSS=CROSS*24.0
READ(17,*) ALFA
WRITE(16,31) ALFA
31 FORMAT(1X,'ALFA =',F8.4)
PI=3.14159

C      READ TEMPERATURE DATA FILE
C
READ(17,10) JUNK2
WRITE(16,*) JUNK2
10 FORMAT(A)

C      TIME CORRECTION
C      SET THE FIRST DAY CROSSING TIME AS TIME ZERO
C
ITER=0
2100 CONTINUE
C      GENERATE SURFACE TEMPERATURE TIME HISTORY

```

```

C
      CALL SURFACE(NP,ITER,DEPTH,SMAX,SMIN,ACMAX,ACMIN,
*     IMAX,IMIN,CROSS)
C
      GIVE INITIAL TEMPERATURE CONDITION
C
      TI=TP(1)
      write(16,*) 'INITIAL TEMPERATURE =',TI
C
      TEMPERATURE PREDICTION
C
      DO 2500 I=1,LAYER
      T1(I,1)=TI
      TT(I,1)=TI
      DO 2400 J=2,np
C
      CALCULATE T1(LAYER,np)
C
      XX=X(I)/(2.*SQRT(ALFA*DY(J)))
      T1(I,J)=TI*ERF(XX)
      T2(I,J)=0.
      DO 2300 K=1,J-1
      BB(K)=(TP(K+1)-TP(K))/(DY(K+1)-DY(K))
      AA(K)=TP(K)-BB(K)*DY(K)
      XXA=X(I)/(2.*SQRT(ALFA*(DY(J)-DY(K))))
      IF(ABS(DY(K+1)-DY(J)).LE.0.001) THEN
        XXB=1.E9
      ELSE
        XXB=X(I)/(2.*SQRT(ALFA*(DY(J)-DY(K+1))))
      ENDIF
      T2A=(AA(K)+BB(K)*DY(J))*ERFC(XXA)+2.*BB(K)*
      & (DY(J)-DY(K))*
      & (XXA*XXA*ERFC(XXA)-XXA*EXP(-XXA*XXA)/SQRT(PI))
      T2B=(AA(K)+BB(K)*DY(J))*ERFC(XXB)+2.*BB(K)*
      & (DY(J)-DY(K+1))*
      & (XXB*XXB*ERFC(XXB)-XXB*EXP(-XXB*XXB)/SQRT(PI))
C
      IF(DY(K+1).EQ.DY(J)) WRITE(16,*) T2A,T2B
      T2(I,J)=T2(I,J)+T2A-T2B
2300  CONTINUE
      TT(I,J)=T1(I,J)+T2(I,J)
2400  CONTINUE
      WRITE(16,2401) I
2401  FORMAT(1X,'I=',I5)
C
      WRITE(16,*) 'J,    T1(I,J),    T2(I,J)'
C
      WRITE(16,*) '(J,T1(I,J),T2(I,J),J=1,NROW)
2500  CONTINUE
C
      OUTPUT DATA FILES
C
      WRITE(16,10) JUNK1
      WRITE(16,2502) LAYER
2502  FORMAT(//1X,'NUMBER OF LAYERS =',I3,/1X,'DEPTH OF EACH LAYER')
      WRITE(16,*) (X(I),I=1,LAYER)
      WRITE(16,2525)
2525  FORMAT(1X,'I,TIME,PRED.SURFACE,L1,L2,L3,L4,L5,')
C

```

```

C      OUTPUT TEMPERATURE IN THE UPPER TWO LAYERS
C
C      DO 2550 I=1,NP
      WRITE(16,2545) I,DY(I),TP(I),TT(1,I),TT(2,I)
2545    FORMAT(1X,I4,1H,4(F5.2,1H,))
2550    CONTINUE
      DIF=0.01
      DO 3000 K=1,LAYER
      DIF1=ABS(DEPTH-X(K))
      IF(DIF1.LT.DIF) THEN
      KD=K
      ELSE
      ENDIF
3000    CONTINUE
C
C      CHECKING MAXIMUM AND MINIMUM TEMPERATURE DIFFERENCE
C
C      DTMAX=SMAX-TT(KD,IMAX)
      DTMIN=SMIN-TT(KD,IMIN)
C      WRITE(16,3001) KD,IMAX,IMIN,ACMAX,ACMIN
C 3001    FORMAT(1X,'KD=',I3,' IMAX=',I3,' IMIN=',I3,/1X,
C      *      ' ACMAX=',F6.3,' ACMIN=',F6.3)
C      WRITE(16,3002) DTMAX,DTMIN
C 3002    FORMAT(1X,' DTMAX=',F6.3,' DTMIN=',F6.3)
      IFLAG=0
      IF(ABS(DTMAX-ACMAX).LT.4.0) GOTO 3080
      ACMAX=DTMAX
      IFLAG=IFLAG+1
3080    CONTINUE
      IF(ABS(-DTMIN-ACMIN).LT.2.0) GOTO 3100
      ACMIN=-DTMIN
      IFLAG=IFLAG+1
3100    CONTINUE
      WRITE(16,3110) ITER,ACMAX,ACMIN
3110    FORMAT(1X,'ITER=',I3,' ACMAX=',F6.3,' ACMIN=',F6.3)
      ITER=ITER+1
      IF(ITER.GT.5) GOTO 4000
      IF(IFLAG.GT.0.9) GOTO 2100
4000    CONTINUE
      CLOSE(15)
      CLOSE(16)
      CLOSE(17)
      STOP
      END
C
C      RETURNS THE ERROR FUNCTION ERF(X)
C
FUNCTION erf(x)
REAL erf,x
REAL gammp
if(x.lt.0.)then
erf=-gammp(.5,x**2)
else
erf=gammp(.5,x**2)
endif
return

```

```

END
  FUNCTION erfc(x)
REAL erfc,x
REAL gammp,gammq
if(x.lt.0.)then
erfc=1.+gammp(.5,x**2)
else
erfc=gammq(.5,x**2)
endif
return
END
  FUNCTION gammp(a,x)
REAL a,gammp,x
REAL gammcf,gamser,gln
if(x.lt.0..or.a.le.0.)pause 'bad arguments in gammp'
if(x.lt.a+1.)then
call gser(gamser,a,x,gln)
gammcp=gamser
else
call gcf(gammcf,a,x,gln)
gammcp=1.-gammcf
endif
return
END
  FUNCTION gammq(a,x)
REAL a,gammq,x
REAL gammcf,gamser,gln
if(x.lt.0..or.a.le.0.)pause 'bad arguments in gammq'
if(x.lt.a+1.)then
call gser(gamser,a,x,gln)
gammq=1.-gamser
else
call gcf(gammcf,a,x,gln)
gammq=gammcf
endif
return
END
  SUBROUTINE gser(gamser,a,x,gln)
INTEGER ITMAX
REAL a,gamser,gln,x,EPS
PARAMETER (ITMAX=100,EPS=3.e-7)
INTEGER n
REAL ap,del,sum,gammeln
gln=gammeln(a)
if(x.le.0.)then
if(x.lt.0.)pause 'x < 0 in gser'
gamser=0.
return
endif
ap=a
sum=1./a
del=sum
do 11 n=1,ITMAX
ap=ap+1.
del=del*x/ap
sum=sum+del

```

```

      if(abs(del).lt.abs(sum)*EPS)goto 1
11    continue
      pause 'a too large, ITMAX too small in gser'
1      gamser=sum*exp(-x+a*log(x)-gln)

      return
      END
      SUBROUTINE gcf(gammcf,a,x,gln)
      INTEGER ITMAX
      REAL a,gammcf,gln,x,EPS,FPMIN
      PARAMETER (ITMAX=100,EPS=3.e-7,FPMIN=1.e-30)
      INTEGER i
      REAL an,b,c,d,del,h,gammln
      gln=gammln(a)
      b=x+1.-a
      c=1./FPMIN
      d=1./b
      h=d
      do 11 i=1,ITMAX
      an=-i*(i-a)
      b=b+2.
      d=an*d+b
      if(abs(d).lt.FPMIN)d=FPMIN
      c=b+an/c
      if(abs(c).lt.FPMIN)c=FPMIN
      d=1./d
      del=d*c
      h=h*del
      if(abs(del-1.).lt.EPS)goto 1
11    continue
      pause 'a too large, ITMAX too small in gcf'

1      gammcf=exp(-x+a*log(x)-gln)*h
      return
      END

      FUNCTION gammln(xx)
      REAL gammln,xx
      INTEGER j
      DOUBLE PRECISION ser,stp,tmp,x,y,cof(6)
      SAVE cof,stp
      cof(1)=76.18009172947146d0
      cof(2)=-86.50532032941677d0
      cof(3)=24.01409824083091d0
      cof(4)=-1.231739572450155d0
      cof(5)=0.1208650973866179d-2
      cof(6)=-.5395239384953d-5
      stp=2.5066282746310005d0
      x=xx
      y=x
      tmp=x+5.5d0
      tmp=(x+0.5d0)*log(tmp)-tmp
      ser=1.000000000190015d0
      do 11 j=1,6
      y=y+1.d0
      ser=ser+cof(j)/y

```

```

11    continue
gammLn=tmp+log(stp*ser/x)

      return
END

C
C      PREDICTION OF MAX & MIN AC SURFACE TEMPERATURE
C
      SUBROUTINE SURFACE(NP,ITER,DEPTH,SMAX,SMIN,ACMAX,
*   ACPIN,IMAX,IMIN,CROSS)
COMMON DY(100),TP(100)
DIMENSION TIME(100),TT(100),T0(100),ST(100)
CHARACTER*9 DATE
CHARACTER*10 TIMER
DOUBLE PRECISION DP
CHARACTER*9 DATEC(100)
CHARACTER*10 TIMEC(100)
DIMENSION DYT(100,2),T(100,4)
WRITE(16,5)
5   FORMAT(//1X,'PREDICTION OF MAX & MIN AC SURFACE TEMPERATURE'//)
IF(ITER.GT.0.9) GOTO 1005
READ(17,*) AMAX,AMIN
READ(17,*) DEPTH,ACMAX,ACMIN
READ(17,*) Z
READ(17,*) TA
READ(17,*) ALFA,CE,CK,CHC,CEA
1005 CONTINUE
WRITE(16,10) AMAX,AMIN
10   FORMAT(1X,'MAXIMUM AIR TEMPERATURE (IN C)',F8.4,
*           /1X,'MINIMUM AIR TEMPERATURE (IN C)',F8.4)
WRITE(16,20) DEPTH,ACMAX,ACMIN
20   FORMAT(1X,'DEPHT(M)=',F8.4,
*           /1X,', MAX AC TEMP.DIFFERENCE IN C=',F8.4,
*           /1X,', MIN AC TEMP.DIFFERENCE IN C=',F8.4)
WRITE(16,30) Z
30   FORMAT(1X,'ZENITH ANGLE IN DEGREES =',F8.4)
WRITE(16,40) TA
40   FORMAT(1X,'Ta VALUE =',F8.4)
WRITE(16,50) ALFA,CE,CK,CHC,CEA
50   FORMAT(1X,'SURFACE ABSORBTIVITY (ALFA)=',F8.4,
*           /1X,'EMMISIVITY OF AC (CE)      =',F8.4,
*           /1X,'THERMAL CONDUCTIVITY (CK)  =',F8.4,
*           /1X,'SURFACE TRANSFER COEF.(CHC)=',F8.4,
*           /1X,'COEF.ATMPH. RADIATION (CEA)=',F8.4)
C      ALFA=0.9
C      CE=0.9
C      CK=1.30
C      CHC=3.5
C      CEA=0.7
      PI=3.1415926
      SGMA=0.1714E-8
C 1005 CONTINUE
      DEPTH=DEPTH*3.281
      ACPIN=ACMAX*9.0/5.0
      ACPIN=ACMIN*9.0/5.0
      IF(ITER.GT.0.9) WRITE(16,*) '**** NEXT ITERATION ****'

```

```

C          PREDICTION OF SURFACE TEMPERATURE (MIN.)
C
C          AA=450.0
C          BB=550.0
C          TS=(AA+BB)/2.0
C          TAIR=AMIN*9.0/5.0+32.0+459.67
1010      CONTINUE
          FX=-CE*SGMA*(TS**4.0)-0.4*CHC*(TS-TAIR)
&           +1.15*CEA*SGMA*(TAIR**4.0)+CK*ACMIN/DEPTH
          FA=-CE*SGMA*(AA**4.0)-0.4*CHC*(AA-TAIR)
&           +1.15*CEA*SGMA*(TAIR**4.0)+CK*ACMIN/DEPTH
          FB=-CE*SGMA*(BB**4.0)-0.4*CHC*(BB-TAIR)
&           +1.15*CEA*SGMA*(TAIR**4.0)+CK*ACMIN/DEPTH
          IF(ABS(FX).LE.0.00001)GOTO 1030
          IF(FX.GT.0.0.AND.FB.GE.FA) BB=TS
          IF(FX.LT.0.0.AND.FB.GE.FA) AA=TS
          IF(FX.GT.0.0.AND.FB.LT.FA) AA=TS
          IF(FX.LT.0.0.AND.FB.LT.FA) BB=TS
          TSA=(AA+BB)/2.0
          IF(ABS(TSA-TS).LT.0.01) THEN
              TS=TSA
              GOTO 1030
          ELSE
              TS=TSA
C              WRITE(16,1022) TS,FX
C 1022      FORMAT(1X,'TS=',F8.3,'  FX=',F8.4)
          END IF
          GOTO 1010
1030      SMIN=5.0*(TS-459.67-32)/9.0
C
C          PREDICTION OF SURFACE TEMPERATURE (MAX)
C
C          Z=ZLATI-20
C          CZ=COS(Z*PI/180.0)
C          AA=500.0
C          BB=650.0
C          TS=(AA+BB)/2.0
C          TAIR=AMAX*9.0/5.0+32.0+459.67
1050      CONTINUE
          FX=442.0*ALFA*(TA**((1/CZ)))*CZ-CE*SGMA*(TS**4.0)-CHC*(TS-TAIR)
&           +CEA*SGMA*(TAIR**4.0)-CK*ACMAX/DEPTH
          FA=442.0*ALFA*(TA**((1/CZ)))*CZ-CE*SGMA*(AA**4.0)-CHC*(AA-TAIR)
&           +CEA*SGMA*(TAIR**4.0)-CK*ACMAX/DEPTH
          FB=442.0*ALFA*(TA**((1/CZ)))*CZ-CE*SGMA*(BB**4.0)-CHC*(BB-TAIR)
&           +CEA*SGMA*(TAIR**4.0)-CK*ACMAX/DEPTH
          IF(ABS(FX).LE.0.00001)GOTO 1090
          IF(FX.GT.0.0.AND.FB.GE.FA) BB=TS
          IF(FX.LT.0.0.AND.FB.GE.FA) AA=TS
          IF(FX.GT.0.0.AND.FB.LT.FA) AA=TS
          IF(FX.LT.0.0.AND.FB.LT.FA) BB=TS
          TSA=(AA+BB)/2.0
          IF(ABS(TSA-TS).LT.0.01) THEN
              TS=TSA
              GOTO 1090
          ELSE

```

```

      TS=TSA
C      WRITE(16,1022) TS,FX
END IF
GOTO 1050
1090 SMAX=5.0*(TS-459.67-32)/9.0
      WRITE(16,*) ''
      WRITE(16,*) 'AIR MAX     AIR MIN     SURFACE MAX     SURFACE MIN'
      WRITE(16,1040) AMAX,AMIN,SMAX,SMIN
1040 FORMAT(1X,4(F8.4,3X))

C      GENERATE THE TEMPERATURE HISTORY ON THE SURFACE
C      (FROM YESTERDAY'S TMIN TO TODAY'S TMIN)
C
      IF(ITER.GT.0.9) GOTO 1099
      READ(17,*) TMIN,TMAX
      WRITE(16,1097) TMIN,TMAX
1097 FORMAT(/1X,'TIME @ MIN. TEMPERATURE (TMIN)=' ,F8.4,
           /1X,'TIME @ MAX. TEMPERATURE (TMAX)=' ,F8.4)
      TMIN=TMIN*24.0
      TMAX=TMAX*24.0
1099 CONTINUE
      SMEAN=0.5*(SMAX+SMIN)
      SAMP=0.5*(SMAX-SMIN)
      S1=TMAX-TMIN
      DO 1100 I=1,49
1100 TIME(I)=TMIN+0.5*FLOAT(I-1)
      TT(1)=SMIN
      DO 1150 I=2,49
      IF(TIME(I).LE.TMAX) THEN
          TT(I)=SAMP*SIN(PI*(TIME(I)-TMIN)/S1-0.5*PI)+SMEAN
      ELSE
          PL=0.85
          PA=0.5*(1.0-PL)
          PM=0.5*(1.0+PL)
          XS1=(TIME(I)-TMAX)/(24.0-S1)
          SN2=PA*COS(2.0*PI*XS1)+PM
          SN1=SIN(2.*PI*((TIME(I)-TMAX)/
          & (2.*(24.-S1))+0.5)-0.5*PI)
          TT(I)=(SAMP*SN1+SMEAN)*SN2
      ENDIF
1150 CONTINUE
C      GENERATE THE TEMPERATURE HISTORY ON THE SURFACE
C      (FROM TODAY'S TMIN TO TODAY'S 4PM)
C
      IF(ITER.GT.0.9) GOTO 1165
      READ(17,*) TMAX1
      WRITE(16,1153) TMAX1
1153 FORMAT(1X,'TIME @ MAX. TEMP. TODAY (TMAX1)=' ,F8.4)
      TMAX1=TMAX1*24.0
C      FROM TODAY'S TMIN TO 1ST TESTING RECORD
C
      READ(17,*) NT
      WRITE(16,1154) NT
1154 FORMAT(1X,'# OF RECORDS IN FWD TESTING (NT)=' ,I4)

```

```

      DO 1158 I=1,NT
      READ(17,*) DP,T(I,2)
1158  DYT(I,2)=DP
      DO 1160 I=1,NT
      T0(I)=24.0*DYT(I,2)
1160  ST(I)=T(I,2)
C      WRITE(16,*) ' T0(I)           ST(I)'
C      WRITE(16,*) (T0(I),ST(I),I=1,NT)
1165  CONTINUE
      TAK=T0(1)-TMIN
      NADD=INT(TAK/0.5)+1
      DT=TAK/FLOAT(NADD)
      NADD1=NADD-1
      DO 1170 I=1,NADD1
1170  TIME(49+I)=TIME(49)+DT*FLOAT(I)
      DO 1180 I=1,NT
      TT(48+NADD+I)=ST(I)
1180  TIME(48+NADD+I)=TIME(49)+T0(I)-TMIN
      S1T=TMAX1-TMIN
      W=SIN(PI*TAK/S1T-0.5*PI)
      U=W+1.
      V=W-1.
      P=2.0*(ST(1)+0.5*SMIN*V)/U
      SAMP1=0.5*(P-SMIN)
      AMEAN=0.5*(P+SMIN)
C      WRITE(16,1182) S1T,TA,P,SAMP1
C 1182  FORMAT(1X,'S1T=',F8.4,'TA=',F8.4,'P=',F8.4,'SAMP1=',F8.4)
      DO 1190 I=1,NADD1
1190  TT(49+I)=SAMP1*SIN(PI*(TIME(49+I)-TIME(49))/S1T-0.5*PI)
      & +AMEAN
      NALL=48+NT+NADD
      WRITE(16,*) ' I,TIME,SURFACE TEMPERATURE'
      WRITE(16,1195) (I,TIME(I),TT(I), I=1,NALL)
1195  FORMAT(1X,I5,1H,,F8.4,1H,,F8.4)
      DO 1200 I=1,NALL-1
      IF(TIME(I).LT.CROSS.AND.TIME(I+1).GE.CROSS) THEN
     INI=I+1
      DY(1)=0.0
      TP(1)=TT(I)+(CROSS-TIME(I))*(TT(I+1)-TT(I))
*    / (TIME(I+1)-TIME(I))
      ELSE
      ENDIF
1200  CONTINUE
      NP=NALL-INI+1
      DO 2010 I=2,np
      DY(I)=TIME(I+INI-1)-CROSS
2010  TP(I)=TT(I+INI-1)
      TM=15.0
      TN=15.0
      NY=NP-NT
      DO 3000 I=1,NY
      IF(ABS(TP(I)-SMAX).LE.TM) THEN
      TM=ABS(TP(I)-SMAX)
      IMAX=I
C      WRITE(16,*) 'DY(I), TP(I), IMAX,
C      WRITE(16,*) DY(I),TP(I),IMAX

```

```
ELSE
ENDIF
IF (ABS(TP(I)-SMIN).LE.TN) THEN
TN=ABS(TP(I)-SMIN)
IMIN=I
C      WRITE(16,*) 'DY(I),  TP(I),  IMIN,' 
C      WRITE(16,*) DY(I),TP(I),IMIN
ELSE
ENDIF
3000 CONTINUE
ACMAX=ACMAX*5.0/9.0
ACMIN=ACMIN*5.0/9.0
C      WRITE(16,3091) IMAX,IMIN,ACMAX,ACMIN
C 3091 FORMAT(1X,'INSIDE SUBROUTINE:',' IMAX=',I3,' IMIN=',I3,/1X,
C      * ' ACPMAX=',F6.3,' ACPMIN=',F6.3)
DEPTH=DEPTH/3.281
RETURN
END
```

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2

0.05714,0.1143

0.3512

0.0055

12.8,-7.6

0.05715,6.0,3.0

48.0

.75

0.9,0.9,1.30,3.5,0.7

0.2919,0.5558

0.5558

16

0.375266,5.8

0.3961,9

0.416933,12.7

0.437766,14.6,

0.4586,17.3

0.479433,19.7

0.500266,21

0.5211,22.7

0.541933,23.4

0.562766,23.5

0.5836,23.2

0.604433,22.7

0.625266,20.7

0.6461,18

0.666933,15

0.687766,12.1

```

C
C***** BUILD UP 7 DAYS TEMPERATURE HISTORY DATA BASE
C
C***** CHARACTER*70 JUNK
CHARACTER*12 IN,ON,ON1,ON2,IN1,IN2,ON3,ON4,ON5
CHARACTER*9 DATEC(2000),DATES(1000),DATEW(1000),CROSD(1000)
CHARACTER*10 TIMEC(2000),TIMES(1000,2)
CHARACTER*9 DATE
CHARACTER*10 TIME,TIME1
COMMON DYT(2000,2),T(2000,4),CROSS(1000,6),TIMN(100,4),
* SUN(1000,3),WHETH(1000,4),TNORM(100,8),TT(2000,2)
REAL*8 A,B
WRITE(*,*) 'INPUT DATE-TEMPERATURE FILE NAME:'
READ(*,'(A)')IN
WRITE(*,*) 'INPUT SUN RISE/SET TIME FILE NAME:'
READ(*,'(A)')IN1
WRITE(*,*) 'INPUT WHETHER INDEX FILE NAME:'
READ(*,'(A)')IN2
WRITE(*,*) 'OUTPUT TEMPERATURE FILE NAME:'
READ(*,'(A)')ON
WRITE(*,*) 'OUTPUT DATE-TIME FILE NAME:'
READ(*,'(A)')ON1
WRITE(*,*) 'OUTPUT CROSSING TIME FILE NAME:'
READ(*,'(A)')ON2
WRITE(*,*) 'OUTPUT SUN RISE/SET TIME&DATE FILE NAME:'
READ(*,'(A)')ON3
WRITE(*,*) 'OUTPUT WHETHER DATA FILE NAME:'
READ(*,'(A)')ON4
WRITE(*,*) 'OUTPUT NORMALIZED TEMPERATURE DATA:'
READ(*,'(A)')ON5
WRITE(*,*) 'INPUT THE SITE ID NUMBER'
WRITE(*,*) '1=PITT,2=CARTERET,3=N.HANOVER,4=DURHAM,5=POLK,',
& '7=WILKES: '
READ(*,*) NSITE
OPEN(15,FILE=IN,STATUS='OLD')
OPEN(14,FILE=IN1,STATUS='OLD')
OPEN(13,FILE=IN2,STATUS='OLD')
OPEN(16,FILE=ON)
OPEN(17,FILE=ON1)
OPEN(18,FILE=ON2)
OPEN(20,FILE=ON3)
OPEN(21,FILE=ON4)
OPEN(22,FILE=ON5)
OPEN(19,FILE='AAA.TXT')

C
C      READ 7 DAYS TEMPERATURE DATA FILE
C
READ(15,10) JUNK
WRITE(*,*) JUNK
READ(15,10) JUNK
WRITE(*,*) JUNK
READ(15,10) JUNK
10    FORMAT(A)

```

```

      II=1
100  READ(15,* ,END=110) DATE,D,TIME,
& A,T(II,1),T(II,2),T(II,3),T(II,4)
      DATEC(II)=DATE
      TIMEC(II)=TIME
      DYT(II,1)=D
      DYT(II,2)=REAL(A)
C      WRITE(19,*) DATEC(II),TIMEC(II),DYT(II,1),DYT(II,2)
      II=II+1
      GOTO 100
110  CONTINUE
      NROW=II-1
      WRITE(*,*) 'NROW=' ,NROW
      DO 150 K=1,NROW
      WRITE(16,120) (T(K,K1),K1=1,4)
150  CONTINUE
120  FORMAT(1X,E10.4,1H,E10.4,1H,E10.4,1H,E10.4)
C      WRITE(19,*) 'WRITE DT AND DYT'
      NDAYS=1
      DO 180 K=1,NROW
      IF(DYT(K,1).GE.34798.0.AND.DYT(K,1).LT.35001.0) DYT(K,2)=
& DYT(K,2)-(1.0/24.0)
      IF(DYT(K,1).GE.35162.0.AND.DYT(K,1).LT.35365.0) DYT(K,2)=
& DYT(K,2)-(1.0/24.0)
C      WRITE(19,*) DATEC(K),DYT(K,1),TIMEC(K),DYT(K,2)
      WRITE(17,190) DATEC(K),DYT(K,1),TIMEC(K),DYT(K,2)
      IF((DYT(K+1,1)-DYT(K,1)).GT.0.99) NDAYS=NDAYS+1
180  CONTINUE
190  FORMAT(1X,A9,1H,F6.0,1H,A10,1H,F8.6)
C
C      READ SUN RISE/SET DATE/TIME
C
      READ(14,11) JUNK
      WRITE(*,*) JUNK
      READ(14,11) JUNK
      WRITE(*,*) JUNK
      READ(14,11) JUNK
      WRITE(*,*) JUNK
11   FORMAT(A)
      IK=1
101  READ(14,* ,END=111) DATE,D,TIME,A,TIME1,B
      DATES(IK)=DATE
      TIMES(IK,1)=TIME
      TIMES(IK,2)=TIME1
      SUN(IK,1)=D
      SUN(IK,2)=REAL(A)
      SUN(IK,3)=REAL(B)
      IF(SUN(IK,2).GE.1.0) SUN(IK,2)=SUN(IK,2)-1.0
      IF(SUN(IK,3).GE.1.0) SUN(IK,3)=SUN(IK,3)-1.0
      IF((D-34798.0).GE.0.0.AND.(D-35001.0).LT.0.0) THEN
      SUN(IK,2)=SUN(IK,2)-(1.0/24.0)
      SUN(IK,3)=SUN(IK,3)-(1.0/24.0)
      ELSE
      END IF
      IF((D-35162.0).GE.0.0.AND.(D-35365.0).LT.0.0) THEN
      SUN(IK,2)=SUN(IK,2)-(1.0/24.0)

```

```

SUN(IK,3)=SUN(IK,3)-(1.0/24.0)
ELSE
END IF
WRITE(19,*) DATES(IK),SUN(IK,1),TIMES(IK,1),SUN(IK,2),
& TIMES(IK,2),SUN(IK,3)
IK=IK+1
GOTO 101
111 CONTINUE
NROWS=IK-1
WRITE(*,*) 'NROWS=',NROWS
DO 151 K=1,NROWS
WRITE(20,121) DATES(K),SUN(K,1),TIMES(K,1),SUN(K,2),
& TIMES(K,2),SUN(K,3)
151 CONTINUE
121 FORMAT(1X,A9,1H,F6.0,1H,A10,1H,F8.6,1H,A10,1H,F8.6)

C
C      READ WHETHER DATA
C
READ(13,12) JUNK
WRITE(*,*) JUNK
READ(13,12) JUNK
WRITE(*,*) JUNK
READ(13,12) JUNK
WRITE(*,*) JUNK
12 FORMAT(A)
IL=1
102 READ(13,* ,END=112) DATE,D,WHETH(IL,2),WHETH(IL,3),WHETH(IL,4)
DATEW(IL)=DATE
WHETH(IL,1)=D
IL=IL+1
GOTO 102
112 CONTINUE
NROWWW=IL-1
WRITE(*,*) 'NROWWW=',NROWWW
DO 152 K=1,NROWWW
WRITE(21,122) DATEW(K),WHETH(K,1),WHETH(K,2),
& WHETH(K,3),WHETH(K,4)
152 CONTINUE
122 FORMAT(1X,A9,1H,F6.0,1H,F5.0,1H,F5.0,1H,F5.0)

C
C      CALCULATING CROSSING TIME
C
L=1
NDAY=1
SAME=0.0
DO 400 I=1,NROW-1
IF(ABS(SAME-DYT(I,1)).LT.0.1.AND.I.GE.2) GOTO 399
NDAY=NDAY+1
A=T(I,3)-T(I,2)
B=T(I+1,2)-T(I+1,3)
IF(A.GE.0.0.AND.B.GE.0.0) THEN
CROSS(L,1)=DYT(I,1)
CROSS(L,2)=(A*DYT(I+1,2)+B*DYT(I,2))/(A+B)
CROSS(L,3)=T(I,2)+((T(I+1,2)-T(I,2))*(CROSS(L,2)-DYT(I,2)))
& /(DYT(I+1,2)-DYT(I,2)))
CROSS(L,4)=T(I,3)+(T(I+1,3)-

```

```

& T(I,3))*(CROSS(L,2)-DYT(I,2))/  

& (DYT(I+1,2)-DYT(I,2))  

CROSD(L)=DATEC(I)  

SAME=CROSS(L,1)  

L=L+1  

ELSE  

ENDIF  

399 CONTINUE  

400 CONTINUE  

LCROS=L-1  

C  

C      CALCULATING DELTA T  

C  

TMEAN=0.0  

DTMN=0  

RDTMN=0  

DO 500 I=1,LCROS  

DO 490 J=1,NROWS  

IF ((ABS(CROSS(I,1)-SUN(J,1))).LT.0.01) THEN  

CROSS(I,4)=CROSS(I,2)-SUN(J,2)  

CROSS(I,5)=CROSS(I,4)/(SUN(J,3)-SUN(J,4))  

ELSE  

ENDIF  

490 CONTINUE  

TMEAN=TMEAN+CROSS(I,2)  

DTMN=DTMN+CROSS(I,4)  

RDTMN=RDTMN+CROSS(I,5)  

500 CONTINUE  

TMEAN=TMEAN/FLOAT(LCROS)  

DTMN=DTMN/FLOAT(LCROS)  

RDTMN=RDTMN/FLOAT(LCROS)  

DO 600 I=1,LCROS  

NOTE=0  

DO 590 J=1,NROWW  

IF ((ABS(CROSS(I,1)-WHETH(J,1))).LT.0.01) THEN  

CROSS(I,6)=WHETH(J,2)  

NOTE=NOTE+1  

ELSE  

ENDIF  

590 CONTINUE  

IF(NOTE.EQ.0) CROSS(I,6)=500.0  

600 CONTINUE  

WRITE(18,410) (CROSD(I),CROSS(I,1),CROSS(I,2),CROSS(I,3),  

& CROSS(I,4),CROSS(I,5),CROSS(I,6),I=1,LCROS)  

410 FORMAT(1X,A9,1H,I5,1H,F8.6,1H,F8.4,1H,F8.6,1H,F8.6,1H,F5.0)  

WRITE(*,*) 'NDAY=',NDAY  

WRITE(*,*) 'LCROS=',LCROS  

C  

C      STATISTIC ANALYSIS AT DIFFERENT WEATHER CONDITIONS  

C  

N500=0  

N80=0  

N20=0  

N0=0  

T500=0.0  

T80=0.0

```

```

T20=0.0
T0=0.0
DT500=0.0
DT80=0.0
DT20=0.0
DT0=0.0
RDT500=0.0
RDT80=0.0
RDT20=0.0
RDT0=0.0
TSTD=0.0
DTSTD=0.0
RDTST=0.0
DO 700 I=1,LCROS
TSTD=TSTD+ (CROSS(I,2)-TMEAN)*(CROSS(I,2)-TMEAN)
DTSTD=DTSTD+ (CROSS(I,4)-DTMN)*(CROSS(I,4)-DTMN)
RDTST=RDTST+ (CROSS(I,5)-RDTMN)*(CROSS(I,5)-RDTMN)
IF (CROSS(I,6).GT.499.0) THEN
N500=N500+1
T500=T500+CROSS(I,2)
DT500=DT500+CROSS(I,4)
RDT500=RDT500+CROSS(I,5)
ELSE IF (CROSS(I,6).LT.100.1.AND.CROSS(I,6).GT.50.0) THEN
N80=N80+1
T80=T80+CROSS(I,2)
DT80=DT80+CROSS(I,4)
RDT80=RDT80+CROSS(I,5)
ELSE IF (CROSS(I,6).LE.50.0.AND.CROSS(I,6).GT.-0.01) THEN
N20=N20+1
T20=T20+CROSS(I,2)
DT20=DT20+CROSS(I,4)
RDT20=RDT20+CROSS(I,5)
ELSE IF (CROSS(I,6).LE.-0.01) THEN
N0=N0+1
T0=T0+CROSS(I,2)
DT0=DT0+CROSS(I,4)
RDT0=RDT0+CROSS(I,5)
END IF
700 CONTINUE
IF(N0.GT.1) T0=T0/FLOAT(N0)
IF(N20.GT.1) T20=T20/FLOAT(N20)
IF(N80.GT.1) T80=T80/FLOAT(N80)
IF(N500.GT.1) T500=T500/FLOAT(N500)
IF(N0.GT.1) DT0=DT0/FLOAT(N0)
IF(N20.GT.1) DT20=DT20/FLOAT(N20)
IF(N80.GT.1) DT80=DT80/FLOAT(N80)
IF(N500.GT.1) DT500=DT500/FLOAT(N500)
IF(N0.GT.1) RDT0=RDT0/FLOAT(N0)
IF(N20.GT.1) RDT20=RDT20/FLOAT(N20)
IF(N80.GT.1) RDT80=RDT80/FLOAT(N80)
IF(N500.GT.1) RDT500=RDT500/FLOAT(N500)
TSTD=SQRT(TSTD/FLOAT(LCROS-1))
DTSTD=SQRT(DTSTD/FLOAT(LCROS-1))
RDTST=SQRT(RDTST/FLOAT(LCROS-1))

C          STATISTICS BASED ON WEATHER INDEX (STD)

```

```

C
TSTD5=0.0
DTSTD5=0.0
RDTST5=0.0
TSTD8=0.0
DTSTD8=0.0
RDTST8=0.0
TSTD2=0.0
DTSTD2=0.0
RDTST2=0.0
TSTD0=0.0
DTSTD0=0.0
RDTST0=0.0
DO 800 I=1,LCROS
  IF (CROSS(I,6).GT.499.0) THEN
    TSTD5=TSTD5+(CROSS(I,2)-T500)*(CROSS(I,2)-T500)
    DTSTD5=DTSTD5+(CROSS(I,4)-DT500)*(CROSS(I,4)-DT500)
    RDTST5=RDTST5+(CROSS(I,5)-RDT500)*(CROSS(I,5)-RDT500)
  ELSE IF (CROSS(I,6).LT.100.1.AND.CROSS(I,6).GT.50.0) THEN
    TSTD8=TSTD8+(CROSS(I,2)-T80)*(CROSS(I,2)-T80)
    DTSTD8=DTSTD8+(CROSS(I,4)-DT80)*(CROSS(I,4)-DT80)
    RDTST8=RDTST8+(CROSS(I,5)-RDT80)*(CROSS(I,5)-RDT80)
  ELSE IF (CROSS(I,6).LE.50.0.AND.CROSS(I,6).GT.-0.01) THEN
    TSTD2=TSTD2+(CROSS(I,2)-T20)*(CROSS(I,2)-T20)
    DTSTD2=DTSTD2+(CROSS(I,4)-DT20)*(CROSS(I,4)-DT20)
    RDTST2=RDTST2+(CROSS(I,5)-RDT20)*(CROSS(I,5)-RDT20)
  ELSE IF (CROSS(I,6).LE.-0.01) THEN
    TSTD0=TSTD0+(CROSS(I,2)-T0)*(CROSS(I,2)-T0)
    DTSTD0=DTSTD0+(CROSS(I,4)-DT0)*(CROSS(I,4)-DT0)
    RDTST0=RDTST0+(CROSS(I,5)-RDT0)*(CROSS(I,5)-RDT0)
  END IF
800  CONTINUE
  IF (N500.GT.1) TSTD5=SQRT(TSTD5/FLOAT(N500-1))
  IF (N500.GT.1) DTSTD5=SQRT(DTSTD5/FLOAT(N500-1))
  IF (N500.GT.1) RDTST5=SQRT(RDTST5/FLOAT(N500-1))
  IF (N80.GT.1) TSTD8=SQRT(TSTD8/FLOAT(N80-1))
  IF (N80.GT.1) DTSTD8=SQRT(DTSTD8/FLOAT(N80-1))
  IF (N80.GT.1) RDTST8=SQRT(RDTST8/FLOAT(N80-1))
  IF (N20.GT.1) TSTD2=SQRT(TSTD2/FLOAT(N20-1))
  IF (N20.GT.1) DTSTD2=SQRT(DTSTD2/FLOAT(N20-1))
  IF (N20.GT.1) RDTST2=SQRT(RDTST2/FLOAT(N20-1))
  IF (N0.GT.1) TSTD0=SQRT(TSTD0/FLOAT(N0-1))
  IF (N0.GT.1) DTSTD0=SQRT(DTSTD0/FLOAT(N0-1))
  IF (N0.GT.1) RDTST0=SQRT(RDTST0/FLOAT(N0-1))
  WRITE(18,*) 'SITE ID = ',NSITE
  WRITE(18,*) 'RECORDING DAYS=',NDAYS
  WRITE(18,*) '      NUMBER CROSSING TIME          DELTA T',
  & '      DELTA RATIO'
  WRITE(18,*) '          MEAN      STD      MEAN      STD ',
  & '      MEAN      STD '
  WRITE(18,185) LCROS,TMEAN,TSTD,DTMN,DTSTD,RDTMN,RDTST
  WRITE(18,186) N80,T80,TSTD8,DT80,DTSTD8,RDT80,RDTST8
  WRITE(18,187) N20,T20,TSTD2,DT20,DTSTD2,RDT20,RDTST2
  WRITE(18,188) N0,T0,TSTD0,DT0,DTSTD0,RDT0,RDTST0
  WRITE(18,189) N500,T500,TSTD5,DT500,DTSTD5,RDT500,RDTST5
185   FORMAT(1X,'ALL ',I3,1H,F8.6,1H,F8.6,1H,F8.6,1H,

```

```

    & F8.6,1H,F8.6)
186  FORMAT(1X,'10050',I3,1H,F8.6,1H,F8.6,1H,F8.6,1H,
    & F8.6,1H,F8.6)
187  FORMAT(1X,'50--0',I3,1H,F8.6,1H,F8.6,1H,F8.6,1H,
    & F8.6,1H,F8.6)
188  FORMAT(1X,'0- -2',I3,1H,F8.6,1H,F8.6,1H,F8.6,1H,
    & F8.6,1H,F8.6)
189  FORMAT(1X,'NOREC',I3,1H,F8.6,1H,F8.6,1H,F8.6,1H,
    & F8.6,1H,F8.6)

C
C          OUTPUT NORMALIZED TEMPERATURE DATA
C
DO 820 I=1,100
TNORM(I,1)=-100.0
TNORM(I,2)=200.0
TNORM(I,3)=0.0
TNORM(I,4)=-100.0
TNORM(I,5)=200.0
820  TNORM(I,3)=0.0
WRITE(22,821)
821  FORMAT(1X,' ',AIR TEMPERATURE,SURFACE TEMPERATURE',
&           /1X,'DATE,DATE#,DAY MAX,DAY MIN,DAY MEAN,',
& 'DAY MAX,DAY MIN,DAY MEAN,DMAX,DMIN,',
& 'TIME@MIN,TIME@MAX,R.T@MIN,R.T@MAX,',
& 'SUN RISE,SUN SET,AM,NOON,PM')
MD=1
MM=1
DO 850 M=1,NROW
TNORM(MM,3)=TNORM(MM,3)+T(M,1)
IF (TNORM(MM,1).LT.T(M,1)) TNORM(MM,1)=T(M,1)
IF (TNORM(MM,2).GT.T(M,1)) TNORM(MM,2)=T(M,1)
TNORM(MM,6)=TNORM(MM,6)+T(M,2)
IF (TNORM(MM,4).LT.T(M,2)) THEN
TNORM(MM,4)=T(M,2)
TIMN(MM,2)=DYT(M,2)
TNORM(MM,7)=T(M,2)-T(M,3)
ELSE
ENDIF
IF (TNORM(MM,5).GT.T(M,2)) THEN
TNORM(MM,5)=T(M,2)
TIMN(MM,1)=DYT(M,2)
TNORM(MM,8)=T(M,2)-T(M,3)
ELSE
ENDIF
IF (ABS(DYT(M+1,1)-DYT(M,1)).GT.0.9) THEN
TNORM(MM,3)=TNORM(MM,3)/FLOAT(MD)
TNORM(MM,6)=TNORM(MM,6)/FLOAT(MD)
DO 822 JS=1,NROWS
IF (ABS(SUN(JS,1)-DYT(M,1)).LT.0.1) THEN
SRISE=SUN(JS,2)
SSET=SUN(JS,3)
TIMN(MM,3)=(TIMN(MM,1)-SRISE)/(SSET-SRISE)
TIMN(MM,4)=(TIMN(MM,2)-SRISE)/(SSET-SRISE)
ELSE
ENDIF
822  CONTINUE

```

```

DO 825 JW=1,NROWW
IF (ABS(WHETH(JW,1)-DYT(M,1)).LT.0.1) THEN
WU1=WHETH(JW,2)
WU2=WHETH(JW,3)
WU3=WHETH(JW,4)
ELSE
ENDIF
825 CONTINUE
WRITE(22,830)DATEC(M),DYT(M,1),TNORM(MM,1),
& TNORM(MM,2),TNORM(MM,3),TNORM(MM,4),TNORM(MM,5),TNORM(MM,6),
& TNORM(MM,7),TNORM(MM,8),
& TIMN(MM,1),TIMN(MM,2),TIMN(MM,3),TIMN(MM,4),
& SRISE,SSET,WU1,WU2,WU3
830 FORMAT(1X,A9,1H,I5,1H,F8.4,1H,F8.4,1H,F8.4,1H,F8.4,1H,
& F8.4,1H,F8.4,1H,F8.4,1H,F8.4,1H,F8.4,1H,F8.4,1H,
& F8.4,1H,F8.4,1H,F8.4,1H,F8.4,1H,F8.4)
MD=1
MM=MM+1
ELSE
MD=MD+1
END IF
850 CONTINUE
MDAY=MM-1
WRITE(22,*) 'DAYS OF RECORDING =',MDAY
MM=1
WRITE(22,*) ' DATE TIME AIR SURFACE'
DO 880 M=1,NROW
TT(M,1)=T(M,1)-TNORM(MM,3)
TT(M,1)=2.0*TT(M,1)/(TNORM(MM,1)-TNORM(MM,2))
TT(M,2)=T(M,2)-TNORM(MM,6)
TT(M,2)=2.0*TT(M,2)/(TNORM(MM,4)-TNORM(MM,5))
C WRITE(22,860) DATEC(M),DYT(M,1),DYT(M,2),TT(M,1),TT(M,2)
C 860 FORMAT(1X,A9,1H,I5,1H,F8.6,1H,F8.4,1H,F8.4)
IF (ABS(DYT(M+1,1)-DYT(M,1)).GT.0.9) MM=MM+1
880 CONTINUE
CLOSE(13)
CLOSE(14)
CLOSE(15)
CLOSE(16)
CLOSE(17)
CLOSE(18)
CLOSE(19)
CLOSE(20)
CLOSE(21)
CLOSE(22)
END

```

APPENDIX A.6

EXAMPLES

Example:

The following example is presented to demonstrate the procedure of FWD temperature predictions and corrections. For easy understanding of the procedure, we give real numbers to the example. The users can follow the procedure and change appropriate variables based on their cases.

The thickness of the AC layer is 114 mm (4.5 inches) at the test site A. The pavement surface temperatures were measured during FWD tests on February 13, 1996 (say today). The crew bought local newspapers of February 13 and 14, 1996. From the newspaper, they found that it was clear and the maximum air temperature was 12.8 °C on Feb. 12. The minimum air temperature was -7.6 °C on Feb. 13, the FWD test day. During FWD tests, the crew found no shade on the test position. Also, the pavement surface is horizontal at the test site.

Based on the field records, the following input data file was generated for the temperature prediction program, PD.for.

Input data file for temperature predictions

```
Line#
1. TEST SITE A, FEB 13, 1996
2. 2
3. 0.05714,0.1143
4. 0.3512
5. 0.0055
6. 12.8,-7.6
7. 0.05715,6.0,3.0
8. 48.0
9. 0.75
10. 0.9,0.9,1.30,3.5,0.7
11. 0.2919,0.5558
12. 0.5558
13. 16
14. 0.375266,5.8
15. 0.3961,9
17. 0.416933,12.7
```

18. 0.437766,14.6,
19. 0.4586,17.3
20. 0.479433,19.7
21. 0.500266,21
22. 0.5211,22.7
23. 0.541933,23.4
24. 0.562766,23.5
25. 0.5836,23.2
26. 0.604433,22.7
27. 0.625266,20.7
28. 0.6461,18
29. 0.666933,15
30. 0.687766,12.1

Table A6.1 User's guide for the program, PD.FOR

Line #	Explanation	Reference
1	Title (anything less than 72 characteristics)	
2	Number of positions to be calculated inside AC layers (less than 10)	
3	Depth of positions to be calculated (in m)	
4	Crossing time (in day)	Table II.2 and Appendix A.3
5	Thermal diffusivity	Table II.3
6	Yesterday's maximum air temperature and today's minimum air temperature (in °C)	Local newspaper or network
7	Depth (m), the initial temperature differences between the surface and this depth at max. and min. air temperatures.	Appendix A.1
8	Zenith angle	Eq. II.28 and Figure II.9
9	Transmission coefficient, τ_a	Table II.3
10	α_1 , ε , k , h_c , ε_a	Table II.3
11	Times at today's min. and yesterday's max. temperature	Table II.1 and Appendix A.1
12	Time at today's max. temperature	Field records or same as yesterday's
13	Number of temperature records during FWD tests	
14 - end	Time (in day), temperature (in °C)	Field records

Example for the demonstration of the temp. prediction procedure

TEST SITE A, FEB 13, 1996
 NUMBER OF DEPTH INTERESTED: LAYER= 2
 DEPTH
 0.571400E-01 0.114300

CROSSING TIME = 0.3512
 ALFA = 0.0055

PREDICTION OF MAX & MIN AC SURFACE TEMPERATURE

MAXIMUM AIR TEMPERATURE (IN C) 12.8000
 MINIMUM AIR TEMPERATURE (IN C) -7.6000
 DEPTH(M)= 0.0571
 MAX AC TEMP.DIFFERENCE IN C= 6.0000
 MIN AC TEMP.DIFFERENCE IN C= 3.0000
 ZENITH ANGLE IN DEGREES = 48.0000
 Ta VALUE = 0.7500
 SURFACE ABSORBTIVITY (ALFA)= 0.9000
 EMMISIVITY OF AC (CE) = 0.9000
 THERMAL CONDUCTIVITY (CK) = 1.3000
 SURFACE TRANSFER COEF.(CHC)= 3.5000
 COEF.ATMPH. RADIATION (CEA)= 0.7000

AIR MAX	AIR MIN	SURFACE MAX	SURFACE MIN
12.8000	-7.6000	22.2110	0.0400

TIME @ MIN. TEMPERATURE (TMIN)= 0.2919
 TIME @ MAX. TEMPERATURE (TMAX)= 0.5558
 TIME @ MAX. TEMP. TODAY (TMAX1)= 0.5558
 # OF RECORDS IN FWD TESTING (NT)= 16

I,TIME,SURFACE TEMPERATURE

1,	7.0056,	0.0400
2,	7.5056,	0.3791
3,	8.0056,	1.3759
4,	8.5056,	2.9694
5,	9.0056,	5.0619
6,	9.5056,	7.5255
7,	10.0056,	10.2093
8,	10.5056,	12.9493
9,	11.0056,	15.5776
10,	11.5056,	17.9335
11,	12.0056,	19.8728
12,	12.5056,	21.2768
13,	13.0056,	22.0596
14,	13.5056,	22.2032
15,	14.0056,	22.0868
16,	14.5056,	21.8336
17,	15.0056,	21.4499
18,	15.5056,	20.9452
19,	16.0056,	20.3316
20,	16.5056,	19.6234
21,	17.0056,	18.8361
22,	17.5056,	17.9858
23,	18.0056,	17.0888
24,	18.5056,	16.1607

25, 19.0056, 15.2156
26, 19.5056, 14.2659
27, 20.0056, 13.3223
28, 20.5056, 12.3927
29, 21.0056, 11.4831
30, 21.5056, 10.5974
31, 22.0056, 9.7376
32, 22.5056, 8.9042
33, 23.0056, 8.0966
34, 23.5056, 7.3141
35, 24.0056, 6.5556
36, 24.5056, 5.8206
37, 25.0056, 5.1094
38, 25.5056, 4.4237
39, 26.0056, 3.7662
40, 26.5056, 3.1411
41, 27.0056, 2.5537
42, 27.5056, 2.0107
43, 28.0056, 1.5191
44, 28.5056, 1.0865
45, 29.0056, 0.7204
46, 29.5056, 0.4275
47, 30.0056, 0.2138
48, 30.5056, 0.0837
49, 31.0056, 0.0400
50, 31.4058, 0.2894
51, 31.8059, 1.0280
52, 32.2061, 2.2267
53, 32.6062, 3.8385
54, 33.0064, 5.8000
55, 33.5064, 9.0000
56, 34.0064, 12.7000
57, 34.5064, 14.6000
58, 35.0064, 17.3000
59, 35.5064, 19.7000
60, 36.0064, 21.0000
61, 36.5064, 22.7000
62, 37.0064, 23.4000
63, 37.5064, 23.5000
64, 38.0064, 23.2000
65, 38.5064, 22.7000
66, 39.0064, 20.7000
67, 39.5064, 18.0000
68, 40.0064, 15.0000
69, 40.5064, 12.1000
INITIAL TEMPERATURE = 2.72461
I= 1
I= 2
PITT COUNTY, FEB 12-13, 1996

NUMBER OF LAYERS = 2
DEPTH OF EACH LAYER
0.571400E-01 0.114300
I,TIME,PRED.SURFACE,L1,L2,L3,L4,L5,
1, 0.00, 2.72, 2.72, 2.72,
2, 0.58, 5.06, 3.37, 2.85,
3, 1.08, 7.53, 4.58, 3.33,
4, 1.58, 10.21, 6.15, 4.12,
5, 2.08, 12.95, 7.94, 5.16,

6, 2.58, 15.58, 9.84, 6.38,
7, 3.08, 17.93, 11.72, 7.71,
8, 3.58, 19.87, 13.48, 9.06,
9, 4.08, 21.28, 15.00, 10.37,
10, 4.58, 22.06, 16.20, 11.55,
11, 5.08, 22.20, 17.01, 12.54,
12, 5.58, 22.09, 17.49, 13.30,
13, 6.08, 21.83, 17.75, 13.87,
14, 6.58, 21.45, 17.85, 14.28,
15, 7.08, 20.95, 17.81, 14.56,
16, 7.58, 20.33, 17.66, 14.72,
17, 8.08, 19.62, 17.39, 14.78,
18, 8.58, 18.84, 17.03, 14.74,
19, 9.08, 17.99, 16.58, 14.61,
20, 9.58, 17.09, 16.07, 14.41,
21, 10.08, 16.16, 15.50, 14.14,
22, 10.58, 15.22, 14.89, 13.81,
23, 11.08, 14.27, 14.24, 13.44,
24, 11.58, 13.32, 13.58, 13.02,
25, 12.08, 12.39, 12.89, 12.58,
26, 12.58, 11.48, 12.21, 12.11,
27, 13.08, 10.60, 11.52, 11.62,
28, 13.58, 9.74, 10.83, 11.12,
29, 14.08, 8.90, 10.16, 10.62,
30, 14.58, 8.10, 9.49, 10.11,
31, 15.08, 7.31, 8.84, 9.59,
32, 15.58, 6.56, 8.20, 9.08,
33, 16.08, 5.82, 7.57, 8.57,
34, 16.58, 5.11, 6.95, 8.07,
35, 17.08, 4.42, 6.35, 7.56,
36, 17.58, 3.77, 5.76, 7.07,
37, 18.08, 3.14, 5.19, 6.58,
38, 18.58, 2.55, 4.65, 6.11,
39, 19.08, 2.01, 4.13, 5.64,
40, 19.58, 1.52, 3.64, 5.20,
41, 20.08, 1.09, 3.19, 4.77,
42, 20.58, 0.72, 2.77, 4.37,
43, 21.08, 0.43, 2.41, 3.99,
44, 21.58, 0.21, 2.10, 3.66,
45, 22.08, 0.08, 1.85, 3.35,
46, 22.58, 0.04, 1.66, 3.09,
47, 22.98, 0.29, 1.60, 2.92,
48, 23.38, 1.03, 1.73, 2.82,
49, 23.78, 2.23, 2.13, 2.85,
50, 24.18, 3.84, 2.81, 3.04,
51, 24.58, 5.80, 3.78, 3.41,
52, 25.08, 9.00, 5.44, 4.17,
53, 25.58, 12.70, 7.58, 5.27,
54, 26.08, 14.60, 9.59, 6.62,
55, 26.58, 17.30, 11.45, 7.94,
56, 27.08, 19.70, 13.38, 9.33,
57, 27.58, 21.00, 15.02, 10.72,
58, 28.08, 22.70, 16.47, 11.97,
59, 28.58, 23.40, 17.68, 13.15,
60, 29.08, 23.50, 18.47, 14.13,
61, 29.58, 23.20, 18.89, 14.88,
62, 30.08, 22.70, 19.03, 15.39,
63, 30.58, 20.70, 18.64, 15.67,
64, 31.08, 18.00, 17.58, 15.54,
65, 31.58, 15.00, 16.04, 15.00,

66,32.08,12.10,14.24,14.15,
ITER= 0 ACMAX= 6.000 ACMIN= 3.000

APPENDIX A.7

AN APPLICATION OF HEAT CONDUCTION THEORY TO PREDICT SUBSURFACE TEMPERATURES IN AN ASPHALT PAVEMENT SYSTEM

1. Introduction

2. Equations For Heat Conduction

3. One-Dimensional Problem In A Semi-Infinite Solid

4. A Semi-Infinite Solid With Uniform Initial Temperature And A Piece-Wise Linear Surface Temperature Variation

5. A Semi-Infinite Solid With A Harmonic Surface Temperature Variation

6. Field Temperature Measurements

7. Prediction Of Subsurface Temperature

8. Concluding Remarks

Appendix I

Appendix II

References

Notations

List of Figures

1. Introduction

There are many practical engineering problems in which the determination of temperature distribution within the system is required. Heat transfer is a field of science which seeks to predict the energy transfer that may take place between systems as a result of a temperature difference. Three modes of heat transfer are normally considered; they are conduction, convection, and radiation. Conduction is the mode of heat transfer in which energy transfer takes place in a system from the hot region to the cold region due to the presence of temperature gradient in the body. The study of conduction heat transfer is principally concerned with the determination of temperature distribution and history within the system.

Obtaining an analytical solution to a general three-dimensional heat conduction problem with specific initial and boundary conditions is, in many cases, not an easy task. However, many practical problems can be modeled reasonably as a one- or two-dimensional system with simplified initial and boundary conditions. Our investigation will be focused on the one-dimensional heat conduction problem in a semi-infinite solid and its application to predict the temperature within a large structural or geotechnical system including a pavement system, a concrete mat, and a soil foundation.

In order to illustrate how the theory can be applied to a real-world problem, the temperature distribution in a pavement system subjected to a random surface temperature variation was predicted using a one-dimensional heat conduction model and then the predicted values were compared with the field measurements. It was shown that a random variation of the surface temperature can conveniently be represented by a piece-wise linear

function in terms of the Heaviside step functions, and a solution for the subsurface temperature field can be obtained analytically.

A special case of the harmonic surface (boundary) temperature variation was also considered as it roughly simulates the daily temperature fluctuation on the ground surface as a result of the daily rotation of the earth. From the analysis of the problem with a harmonic boundary condition, some useful information on the propagation of temperature wave (including the time lag, propagation speed, and wavelength) was obtained and compared with the field measurements.

In a flexible (or asphalt concrete) pavement system, the mechanical properties of the asphalt layer is temperature-dependent and the deformation response of the pavement system to a given loading depends on the temperature of the asphalt layer (Ullidtz 1987).

In a rigid (or Portland cement concrete) pavement system, cracking takes place as a result of the combination of repeated traffic loading and thermal cycling; hence knowing the temperature in the surface concrete layer is important in analyzing its thermo-mechanical response (Huang 1993).

The methods of predicting the temperature in a pavement layer have been suggested by several researchers and organizations (e.g., Southgate and Deen 1969, Barker et al. 1977, AASHTO 1993). However, most of these approaches are based on a stochastic process and simplifying assumptions with a view to practicality. Dempsey et al. (1985) developed a one-dimensional, numerical (finite-difference), heat-transfer model to predict the temperature distribution within the pavement system. The model uses the properties of convection, conduction, and radiation to simulate the movement of heat (or temperature gradient) from the atmosphere to and through the pavement system.

In the present paper, a simple heat conduction-based model for an analytical prediction of subsurface temperature within a semi-infinite system (including a pavement system) from a measured surface temperature history was presented. Both arbitrary (or random) and harmonic surface temperature histories were considered. Emphasis was placed on providing a theoretical basis on which more realistic and accurate prediction models may be established.

First, the field equations and the accompanying conditions needed to formulate a general heat conduction boundary value problem were briefly reviewed and the solutions to a class of one-dimensional problems were retrieved from the literature. Then, based on these, an explicit analytical solution for the subsurface temperature distribution of a semi-infinite solid subjected to a piece-wise linear boundary temperature history (typically given by actual field measurements at discrete time intervals) was developed and applied to predict the temperature within a pavement system.

2. Equations For Heat Conduction

The mathematical representation of a heat conduction problem has been established based on general thermodynamic principles and phenomenological observations and is given in many textbooks (e.g., Schneider 1955, Carslaw and Jaeger 1959, Özisik 1993). The basic equations and conditions that constitute a heat conduction problem in an isotropic and homogeneous body are given in the following:

Field Equations:

$$-\underline{\nabla} \cdot \underline{q} + q_i = \rho c \dot{T} \quad (\text{energy balance}) \quad (1)$$

$$\underline{g} = \underline{\nabla} T \quad (\text{temperature gradient}) \quad (2)$$

$$\underline{q} = -k \underline{g} \quad (\text{Fourier law}). \quad (3)$$

Initial Condition:

$$T = G(\underline{x}) \quad \text{in } V \text{ and } t=0. \quad (4)$$

Boundary Conditions:

$$T = F_1(\underline{x}, t) \quad \text{on } S_1 \text{ and } t>0 \quad (5)$$

$$k \frac{\partial T}{\partial n} = F_2(\underline{x}, t) \quad \text{on } S_2 \text{ and } t>0. \quad (6)$$

The symbols and notations used in the above equations are identified in the following:

$T = T(\underline{x}, t)$ = temperature ($^{\circ}\text{C}$),

\underline{g} = temperature gradient vector ($^{\circ}\text{C}/\text{m}$),

\underline{q} = heat flux vector (W/m^2),

q_I = rate of internal heat generation per unit volume (W/m^3),

k = thermal conductivity ($\text{W/m}\cdot\text{^\circ C}$),

ρ = mass density (kg/m^3),

c = specific heat ($\text{J/kg}\cdot\text{^\circ C}$),

\underline{x} = spatial coordinates ($= x\underline{i} + y\underline{j} + z\underline{k}$ in Cartesian coordinates) (m), and

t = time (sec).

More symbols are explained in Notations in page A-87.

When Equations (2) and (3) are substituted into (1), the following *heat conduction equation* for a homogeneous isotropic solid with internal heat generation is obtained:

$$\underline{\nabla} \cdot (k \underline{\nabla} T) + q_I = \rho c \dot{T}. \quad (7)$$

Any heat conduction problem can be represented mathematically by the governing equation (7) and accompanying initial and boundary conditions (4)-(6). For those readers who are familiar with elastodynamic problems, there is a useful correspondence between the mathematical representations of heat conduction and elastodynamics; Equations (1)-(3) and (7) correspond to the equation of motion, strain-displacement relationship, Hooke's law, and Navier's equation, respectively, of an elastodynamic boundary value problem. Further, the primary variables, temperature and heat flux, correspond to displacement and stress, respectively.

When the thermal conductivity k is assumed to be constant, (7) reduces to

$$\nabla^2 T + \frac{q_I}{k} = \frac{\dot{T}}{\alpha} \quad (8)$$

where

$$\alpha = \frac{k}{\rho c} = \text{thermal diffusivity} \quad (9)$$

with a dimension of m^2/sec or m^2/hour . The thermal diffusivity is an indicator of the propagation speed of heat in the medium during changes of temperature with time. The greater the thermal diffusivity, the faster is the propagation of heat.

Equation (8) further reduces to the so-called *diffusion* (or Fourier) equation if there is no heat generation within the system,

$$\nabla^2 T = \frac{\dot{T}}{\alpha}. \quad (10)$$

The Cartesian coordinate system may be used advantageously for bodies with rectangular boundaries, in which case (10) becomes

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t}. \quad (11)$$

Methods of solving various kinds of heat conduction problems are given in the literature.

3. One-Dimensional Problem In A Semi-Infinite Solid

A one-dimensional heat conduction problem for a semi-infinite solid with a constant thermal conductivity and without an internal heat generation may be defined by the following equations and conditions, which are reduced from the general three-dimensional formulations, (11) and (4)-(6), respectively:

Field Equations:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t} \quad \text{for } x>0, t>0. \quad (12)$$

Initial Condition:

$$T = G(x) \quad \text{for } x \geq 0, t=0. \quad (13)$$

Boundary Condition:

$$T = F(t) \quad \text{for } x=0, t>0. \quad (14)$$

Only the temperature-prescribed boundary condition is considered, which simulates the boundary conditions of many practical problems. The heat flux-prescribed boundary condition may also be handled without difficulties. In the remainder of this paper, our discussion will be confined to the type of problems that can be represented by (12)-(14), with an application of the theory to predict the subsurface temperature in a

pavement or a foundation system in mind. The problem is schematically represented in Fig. 1.

The problem given by (12)-(14) is linear in T and therefore we may make use of the property of *superposition* in finding the solution $T(x,t)$ for the given initial and boundary conditions. Specifically, if we let

$$T(x,t) = T_1(x,t) + T_2(x,t) \quad (15)$$

then it can be shown that T_1 and T_2 must satisfy a partial-differential equation of the same form as (12), but with simplified initial and boundary conditions, i.e.,

$$\frac{\partial^2 T_1}{\partial x^2} = \frac{I}{\alpha} \frac{\partial T_1}{\partial t} \quad \text{for } x > 0, t > 0 \quad (16)$$

$$T_1 = G(x) \quad \text{for } x \geq 0, t = 0 \quad (17)$$

$$T_1 = 0 \quad \text{for } x = 0, t > 0. \quad (18)$$

and

$$\frac{\partial^2 T_2}{\partial x^2} = \frac{I}{\alpha} \frac{\partial T_2}{\partial t} \quad \text{for } x > 0, t > 0 \quad (19)$$

$$T_2 = 0 \quad \text{for } x \geq 0, t=0 \quad (20)$$

$$T_2 = F(t) \quad \text{for } x=0, t>0. \quad (21)$$

The solution to the problem defined by (16)-(18) is already known (e.g., Özisik 1993) and is given by

$$T_1(x, t) = \frac{1}{2\sqrt{\pi\alpha t}} \int_0^\infty G(\xi) \left[\exp\left(-\frac{(x-\xi)^2}{4\alpha t}\right) - \exp\left(-\frac{(x+\xi)^2}{4\alpha t}\right) \right] d\xi. \quad (22)$$

The solution to the problem defined by (19)-(21) is also available (Özisik 1993) and is given by

$$T_2(x, t) = \frac{x}{2\sqrt{\pi\alpha}} \int_0^\infty \frac{F(\tau)}{(t-\tau)^{3/2}} \exp\left(-\frac{x^2}{4\alpha(t-\tau)}\right) d\tau \quad (23)$$

or, in an alternative form,

$$T_2(x, t) = \frac{2}{\sqrt{\pi}} \int_{\frac{x}{2\sqrt{\alpha t}}}^\infty F\left(t - \frac{x^2}{4\alpha\eta^2}\right) e^{-\eta^2} d\eta \quad (24)$$

where the variables τ in (23) and η in (24) are related as follows:

$$\eta = \frac{x}{2\sqrt{\alpha(t-\tau)}}. \quad (25)$$

The solution to the original problem defined by (12)-(14) is then obtained by superposing (22) and (23) or (24) by (15).

4. A Semi-Infinite Solid With Uniform Initial Temperature And A Piece-Wise Linear Surface Temperature Variation

We have discussed the mathematical representation of a one-dimensional heat conduction problem in a semi-infinite solid with general initial and boundary conditions and retrieved its solution from the literature. The solutions (22) and (23) or (24) are applicable to any prescribed initial and boundary conditions; however, carrying out the required integrations analytically is not an easy task unless the specified initial or boundary condition can be represented by a simple function. Therefore, in order to find a closed-form solution (without resorting to a numerical procedure such as the finite-difference or the finite-element method), the actual initial and boundary conditions must be appropriately simplified. Fortunately, many practical problems can be modeled with simplified initial and/or boundary conditions with a reasonable accuracy. For instance, the assumption of a uniform initial temperature distribution throughout the domain of the problem is not a bad assumption in solving some one-dimensional, semi-infinite solid problems, especially when the solution is sought for a time which is much remote from the initial time (at which $t=0$). The boundary conditions, however, are usually much more variable from one problem to another. In some cases, the boundary condition for a semi-infinite solid problem consists of a piece-wise linear surface temperature variation given usually by actual measurements at appropriate time intervals. It will be shown in this paper

that, when the boundary condition is represented by a piece-wise linear function, a solution can be obtained by carrying out the integration in (24) analytically.

First, let us consider the case of a uniform initial temperature distribution with constant boundary temperature of zero degree; say, $G(x) = T_i = \text{constant}$ and $F(t) = 0$. Substituting $G(\xi) = T_i$ in (22) and carrying out the integral, one can obtain the following solution:

$$T_i(x, t) = T_i \operatorname{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right) \quad (26)$$

where

$$\operatorname{erf}(X) = \frac{2}{\sqrt{\pi}} \int_0^X e^{-\xi^2} d\xi = \text{error function.} \quad (27)$$

Next, let us consider the case of a random boundary temperature variation with uniform initial temperature of zero degree; say, $G(x) = 0$ and $F(t) = \text{a piece-wise linear function in } t$. We shall first represent the actual variation of the surface temperature in a piece-wise linear function. Using the symbols and the geometry given in Fig. 2, the following functional expression can be obtained to represent the piece-wise linear description of the surface temperature variation:

$$F(t) = \sum_{i=1}^n F_i(t) [H(t - t_i) - H(t - t_{i+1})] \quad (28)$$

where

$$F_i(t) = A_i + B_i t \quad \text{for } t_i \leq t < t_{i+1} \quad (i = 1, 2, \dots, n), \quad (29)$$

$$B_i = \frac{T_{i+1} - T_i}{t_{i+1} - t_i}, \quad A_i = T_i - B_i(t_i - t_1) \quad (\text{no sum on } i; \quad i = 1, 2, \dots, n), \quad (30)$$

$$H(t) = \begin{cases} 1 & \text{for } t > 0 \\ 0 & \text{for } t < 0 \end{cases} \quad (\text{the Heaviside step function}), \quad (31)$$

and T_i = measured surface temperature at the corresponding time t_i , with $t_1 = 0$ and $t_{n+1} = t$ (the current time) where $(n+1)$ is the total number of measurements up to the current time.

Substituting (28) into (24)

$$T_2(x, t) = \frac{2}{\sqrt{\pi}} \int_{\frac{x}{2\sqrt{\alpha t}}}^{\infty} \sum_{i=1}^n \left[F_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) \left\{ H(t - \frac{x^2}{4\alpha\eta^2} - t_i) - H(t - \frac{x^2}{4\alpha\eta^2} - t_{i+1}) \right\} \right] e^{-\eta^2} d\eta \quad (32)$$

or

$$T_2(x, t) = \frac{2}{\sqrt{\pi}} \sum_{i=1}^n \left[\int_{\frac{x}{2\sqrt{\alpha(t-t_i)}}}^{\infty} F_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) e^{-\eta^2} d\eta - \int_{\frac{x}{2\sqrt{\alpha(t-t_{i+1})}}}^{\infty} F_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) e^{-\eta^2} d\eta \right]. \quad (33)$$

The step from (32) to (33) requires the use of the definition of the Heaviside step function and a special property associated with an integral in which a step function is included as part of its integrand (see Appendix I for derivation). Now (33) may be evaluated by substituting $F_i(t)$ defined by (29) into each term in (33). The end result can conveniently be

expressed in terms of complementary error functions and exponential functions as follows
(see Appendix II for derivation):

$$T_2(x, t) = \sum_{i=1}^n \left[\left\{ (A_i + B_i t) \operatorname{erfc}(X_i) + 2B_i(t - t_i) \left(X_i^2 \operatorname{erfc}(X_i) - \frac{X_i}{\sqrt{\pi}} e^{-X_i^2} \right) \right\} - \left\{ (A_i + B_i t) \operatorname{erfc}(X_{i+1}) + 2B_i(t - t_{i+1}) \left(X_{i+1}^2 \operatorname{erfc}(X_{i+1}) - \frac{X_{i+1}}{\sqrt{\pi}} e^{-X_{i+1}^2} \right) \right\} \right] \quad (34)$$

where

$$X_i = \frac{x}{2\sqrt{\alpha(t - t_i)}} \quad \text{and} \quad X_{i+1} = \frac{x}{2\sqrt{\alpha(t - t_{i+1})}}, \quad (35)$$

$$\operatorname{erfc}(X) = \frac{2}{\sqrt{\pi}} \int_X^\infty e^{-\xi^2} d\xi = \text{complementary error function}, \quad (36)$$

and A_i and B_i are as defined in (30).

For a special case of the *constant* surface temperature, $F(t)=T_0=\text{constant}$, from (34) with $A_i = T_0$ and $B_i = 0$ for $i = 1, 2, \dots, n$,

$$T_2(x, t) = T_0 \sum_{i=1}^n [\operatorname{erfc}(X_i) - \operatorname{erfc}(X_{i+1})] = T_0 [\operatorname{erfc}(X_1) - \operatorname{erfc}(X_{n+1})] \quad (37)$$

or

$$T_2(x,t) = T_o \operatorname{erfc}\left(\frac{x}{2\sqrt{\alpha t}}\right) \quad (38)$$

as $X_1 = x / 2\sqrt{\alpha(t - t_1)} = x / 2\sqrt{\alpha t}$ and $X_{n+1} = x / 2\sqrt{\alpha(t - t_{n+1})} \rightarrow \infty$ with $t_1 = 0$ and $t_{n+1} = t$. The solution (38) coincides with that reported in the literature (e.g., Özisik 1993).

The final solution to the problem of the semi-infinite solid with uniform initial temperature and a piece-wise linear surface temperature variation is obtained by combining (26) and (34) according to (15). The solutions (26) and (38) to the problems with the uniform initial temperature and the constant boundary temperature, respectively, are plotted in Fig. 3.

5. A Semi-Infinite Solid With A Harmonic Surface Temperature Variation

A special case of transient boundary conditions that is of particular interest is the regular harmonic boundary condition. This type of boundary condition typically occurs on the earth surface as the result of daily and annual temperature fluctuations which repeat themselves due to periodic heating by the Sun. The determination of temperature or heat flow within a system on the earth surface (such as pavement system, concrete mat, or soil foundation) subjected to an idealized daily or annual harmonic surface temperature variation can be made analytically.

The solution to problems with a harmonic boundary condition can be obtained by substituting the mathematical representation of the harmonic boundary temperature

variation into the general solution (24). Consider a semi-infinite solid with a sinusoidal surface temperature variation $F(t)$ in the following form:

$$F(t) = T_0 + \Delta T \cos(\omega t - \beta) \quad (39)$$

where T_0 is the mean temperature, ΔT is the amplitude, ω is the angular frequency (or angular speed), and β is the phase angle. The function $F(t)$ in (39) is schematically represented in Fig. 4.

Substituting (39) into (24), one obtains

$$T_2(x, t) = \frac{2}{\sqrt{\pi}} \int_{\frac{x}{2\sqrt{\alpha t}}}^{\infty} \left[T_0 + \Delta T \cos\left\{\omega\left(t - \frac{x^2}{4\alpha\eta^2}\right) - \beta\right\}\right] e^{-\eta^2} d\eta \quad (40)$$

or

$$\begin{aligned} T_2(x, t) = & T_0 \frac{2}{\sqrt{\pi}} \int_{\frac{x}{2\sqrt{\alpha t}}}^{\infty} e^{-\eta^2} d\eta + \Delta T \frac{2}{\sqrt{\pi}} \int_0^{\infty} \cos\left\{\omega\left(t - \frac{x^2}{4\alpha\eta^2}\right) - \beta\right\} e^{-\eta^2} d\eta \\ & - \Delta T \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{\alpha t}}} \cos\left\{\omega\left(t - \frac{x^2}{4\alpha\eta^2}\right) - \beta\right\} e^{-\eta^2} d\eta \end{aligned} \quad (41)$$

The first integral can be represented in terms of the complementary error function defined by (36), and the second integral can be evaluated analytically (Carslaw and Jaeger 1959); then (41) becomes

$$\begin{aligned}
T_2(x, t) = & T_0 \operatorname{erfc} \left(\frac{x}{2\sqrt{\alpha t}} \right) + \Delta T \exp \left[-x \sqrt{\frac{\omega}{2\alpha}} \right] \cos \left[\omega t - x \sqrt{\frac{\omega}{2\alpha}} - \beta \right] \\
& - \Delta T \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{\alpha t}}} \cos \left\{ \omega \left(t - \frac{x^2}{4\alpha \eta^2} \right) - \beta \right\} e^{-\eta^2} d\eta
\end{aligned} \tag{42}$$

Schneider (1955) obtained, by applying the method of separation of variables, the steady-state part of the solution (the second term on the right of (42)). Carslaw and Jaeger (1959) and Özisik (1993) gave (42) without including the effects of the mean temperature T_0 (the first term on the right hand side). The first term on the right of (42) approaches asymptotically to T_0 and the third term which represents the transients dies away as $t \rightarrow \infty$ for finite x . Therefore, when the semi-infinite solid has been subjected to the harmonic surface temperature (39) long enough so that the transient state has passed and the effects of initial temperature have vanished, the temperature field in the solid can be given by the following periodic function:

$$T(x, t) = T_0 + \Delta T \exp \left(-x \sqrt{\frac{\omega}{2\alpha}} \right) \cos \left(\omega t - x \sqrt{\frac{\omega}{2\alpha}} - \beta \right). \tag{43}$$

Compared to (39), the temperature field (43) indicates that its mean temperature and angular frequency remain unchanged but its amplitude decays exponentially with depth and it becomes out of phase with the surface temperature by a phase angle of $x\sqrt{\omega/2\alpha}$. Equation (43) is plotted in Figs. 5 and 6 for the temperature variation with time at selected depths and the temperature distribution with depth at selected instances, respectively, and will later be compared with the filed measurements (see Figs. 9 and 10 in the next section).

It is seen in Fig. 5 that the amplitudes of the internal temperature wave diminish exponentially with depth. The rate of decaying of the amplitude is also dependent upon the wave frequency ω . Fig. 6 shows in a different way that not only the amplitudes reduce but the out-of-phase angles increase with increasing depth.

The *time lag* of the temperature wave can be computed by dividing the out-of-phase angle by the angular speed as follows:

$$\Delta t = \frac{x\sqrt{\omega/2\alpha}}{\omega} = x\sqrt{\frac{I}{2\alpha\omega}} = \frac{x}{2}\sqrt{\frac{P}{\pi\alpha}} \quad (44)$$

where $P = 2\pi/\omega$ is the period of the temperature wave; for examples, for the typical daily temperature oscillation, $P = 24$ hours, and for the annual temperature oscillation, $P = 365$ days, may be adopted. For a given depth, the time lag is seen to be proportional to the square root of the wave period. The *speed* at which the temperature wave propagates into the medium can be obtained by the following:

$$v = \frac{x}{\Delta t} = \sqrt{2\alpha\omega} = 2\sqrt{\frac{\pi\alpha}{P}}. \quad (45)$$

The *wavelength* of the temperature wave can be determined by multiplying the wave speed by the period (which is the time required for the wave to travel one complete cycle); that is,

$$\lambda = vP = \pi \sqrt{\frac{8\alpha}{\omega}} = 2\sqrt{\pi\alpha P} . \quad (46)$$

For instance, the wavelength λ gives the depth a daily surface temperature fluctuation propagates into the ground within a day with $P = 24$ hours.

6. Field Temperature Measurements

In order to check the applicability of the theoretical solutions based on heat conduction principles to predict the temperature variation in a pavement system, a field temperature measurement program has been conducted. The program consisted of measuring the temperatures of the ambient air, the pavement surface, and the pavement layer at different depths. The measurements were made every half an hour over a period of approximately seven days on several selected sites in North Carolina during the month of August. The J-type thermocouples wired to an automated in-situ data acquisition system were used in measuring the temperatures. The subsurface temperatures were measured through the thermocouples buried at different selected depths.

Some typical measurements are plotted in Figs. 7 and 8, which were obtained from two different sites (which will be referred to as Site A and Site B, respectively). The time-history of temperatures, of the air, the pavement surface, the asphalt concrete (AC) layer at its one-third depth (from the surface), and the AC layer at its bottom, are shown in each figure. The times, $t = 24, 48, 72, \dots$ hours correspond to 12:00 am (midnight) in Eastern Standard Time. The pavement structure on Site A and Site B consists of an AC reinforcing layer underlain by a subgrade layer. The thicknesses of the AC layer on Site A

and Site B are 25.4 cm (10 inches) and 30.5 cm (12 inches), respectively. The weather conditions during the measuring period were generally sunny on Site A and alternating sunny and rainy on Site B (rainy conditions on Site B during $24 < t < 48$ and $96 < t < 168$). Overall, each temperature curve under normal weather condition roughly simulates a sinusoidal variation with a period of 24 hours. The amplitudes decrease with depth. Each curve is out of phase with each other by a different amount of time; an increasing time lag is observed with increasing depth.

In order to view the characteristics of each curve more closely, the plot was represented in Figs. 9 and 10 focusing on a typical one-day measurement (for $39 < t < 63$ from Fig. 7). It was observed that the peak surface temperature occurred at around 3 pm (in summer day-light saving time). The overall trends of the curves in Figs. 9 and 10 compare quite well with those in Figs. 5 and 6 at least qualitatively. In our case, the period $P = 2\pi/\omega = 24$ hours, and the phase angle $\beta = \omega(39) = (2\pi/24)(39) = 10.21$ radians. No actual measurement of the thermal diffusivity of the asphalt concrete was made; instead, a typical value, $\alpha = 0.0037 \text{ m}^2/\text{hour} = 1.03 \times 10^{-6} \text{ m}^2/\text{sec}$ (with $k = 1.45 \text{ W/m} \cdot ^\circ\text{C}$, and $\rho c = 1.41 \times 10^6 \text{ J/m}^3 \cdot ^\circ\text{C}$), given by Yoder and Witczak (1975), was used. It will be seen later that, with this value of α , a fairly good prediction of subsurface temperature can be made. The abscissa $x\sqrt{\omega/2\alpha} = \pi/2$ in Fig. 6 corresponds to $x = 264 \text{ mm}$ in Fig 10.

Approximate values of the time lag, the propagation speed, and the wavelength of the temperature wave can be computed from (44) - (46), respectively, assuming the surface temperature varies in a harmonic function, i.e.,

$$\Delta t = \frac{x}{2} \sqrt{\frac{P}{\pi\alpha}} = \frac{x}{2} \sqrt{\frac{24}{\pi(0.0037)}} = 22.7x \text{ (in hours when } x \text{ is in meters)}, \quad (47)$$

$$v = 2\sqrt{\frac{\pi\alpha}{P}} = 2\sqrt{\frac{\pi(0.0037)}{24}} = 0.044 \text{ m/hour}, \quad (48)$$

and

$$\lambda = 2\sqrt{\pi\alpha P} = 2\sqrt{\pi(0.0037)(24)} = 1.056 \text{ m.} \quad (49)$$

The result (47) agrees quite well with the actual observation. In Fig. 9, it is seen that the peak temperatures at $x = 0$, 85, and 254mm occur respectively at around $t = 39$, 41, and 45 hours giving time lags (relative to $x = 0$) of 2 and 6 hours at $x = 85$ and 254mm, respectively. The computed time lags for $x = .085$ and .254 m are 1.93 and 5.77 hours, respectively, according to (47). The theoretical wavelength (49) also appears to be in a reasonable agreement with the actual one shown in Fig. 10, where only about a quarter wavelength of each curve is given.

7. Prediction Of Subsurface Temperature

In order to assess the applicability of the theory discussed above, the temperatures in the real pavement layer will be predicted using (15), (26), and (34) and then be compared with the measured data.

Fig. 11 shows the predicted temperature variations (represented in continuous lines) in comparison with the corresponding field measurements (represented in symbols)

at the one-third depth and at the bottom of the AC layer on Site A. The one-third depth of the AC layer was chosen as the temperature at that depth is often used as the representative temperature of the layer by pavement engineers. It was assumed that the initial temperature distribution was uniform throughout the entire depth of the semi-infinite system and the system was subjected to a random surface temperature variation which was defined by the actual temperature readings taken on the surface (see the surface temperature measurements given in Fig. 7). An initial temperature of $T_i = 32^\circ\text{C}$, which is the average of the one-third and the bottom AC layer temperatures at the start of the measurement ($t = 12$ hours), was adopted and substituted into (26). The influence of the initial temperature dies away as the time elapses. The surface temperature variation was represented by a piece-wise linear function given by (28) and substituted into (34). The final predicted temperature was obtained by (15) and is plotted in Fig. 11. The theoretical prediction was in good agreement with the measurements. Some discrepancies observed at the peaks and the bottoms of the curves are believed to be due to the use of an estimated value for the thermal diffusivity. It will be shown in a later discussion that these discrepancies can be reduced by using a different value of α . It is to be noted that the entire surface temperature readings from the start of the measurement up to the current time were used as the boundary condition in predicting the subsurface temperature at the current time. However, it is understood from the theory that the influence of the remote past history of the surface temperature on the current subsurface temperature is negligible (which is analogous, in nature, to the *principle of fading memory* (Truesdell and Noll 1965) postulated in the constitutive theory of a viscoelastic material). Therefore, in practice, only the surface temperature history for a limited time duration and the initial

temperature need to be known to predict the current value of the subsurface temperature.

A thermal diffusivity of $\alpha = 0.0037 \text{ m}^2/\text{hour}$ was used.

The same procedure was followed in predicting the subsurface temperature on Site B, and the results are presented in Fig. 12. Because of the changing weather conditions, the temperature curves are highly irregular especially during the rainy days and the predicting these temperature variations was expected to be a challenging task. However, the results were in a good agreement with the field measurements. Some minor disagreements were noticed at the bottom of the AC layer especially when the temperature was increasing. A uniform initial temperature of $T_i = 33^\circ\text{C}$, which is the average of the one-third and the bottom AC layer temperatures at the start of the measurement, was used. A thermal diffusivity of $\alpha = 0.0037 \text{ m}^2/\text{hour}$ was used.

In order to investigate the effects of the initial temperature on the subsurface temperature prediction, a different value of T_i was tried. A uniform initial temperature of 40°C , which is close to the average of the daily surface temperature variation, was arbitrarily adopted and the resulting prediction for Site A are shown in Fig. 13. Other input parameters were the same as those used for the predictions shown in Fig. 11. It is seen that the discrepancy due to the unreasonable initial temperature is more pronounced at a greater depth of the pavement layer, which can be understood from (26). According to (26), the greater the depth and the shorter the time elapsed, the greater is the influence of T_i on $T_1(x,t)$. The predicted temperature at the one-third depth of the AC layer is seen to be much less dependent on T_i than at the bottom of the layer. However, it is seen that the influence of T_i is significant even at the one-third depth during the early hours (when time t is close to the initial time t_1); therefore, adopting a correct T_i is important especially

when the boundary temperature data are available only over a short period of time from the initial time. Currently, an investigation is being carried out by the authors to develop a method for estimating an initial temperature distribution based on the known surface temperature history.

Finally, the effect of thermal diffusivity on the subsurface temperature prediction was studied by trying values of α different from that taken from the literature. The predicted temperature variation for Site A using $\alpha = 0.003 \text{ m}^2/\text{hour}$ is given in Fig. 14; it is seen that the prediction at the one-third depth is improved, yet at the bottom of the layer the prediction quality appears to be slightly lessened. For Site B, the value $\alpha = 0.0037 \text{ m}^2/\text{hour}$ appears to be good enough and no noticeable improvement was achieved with different values of α .

8. Concluding Remarks

A one-dimensional heat conduction model for a semi-infinite solid with uniform initial temperature and a random surface temperature variation has been shown to accurately predict the subsurface temperature distribution in a pavement system. A mathematical representation of a random surface temperature history in terms of a piece-wise linear function has been successfully applied to develop an explicit analytical solution model. The accuracy of the model was verified by comparing the predicted subsurface temperatures with those measured at different depths and times within the asphalt concrete layer of a flexible pavement system. The success of prediction requires a knowledge of the surface temperature history up to the current time and a reasonable estimation of the initial temperature and the thermal diffusivity of the medium.

Under normal weather conditions, it was found from field measurements that the daily surface temperature variation roughly simulates a periodic harmonic function. Under a harmonic surface temperature variation, the subsurface temperature also varies harmonically with time but with a finite phase angle and with an amplitude diminishing exponentially with depth. In addition, from the analysis of this case of the idealized harmonic temperature variation with time, the values of the time lag, the propagation speed, and the wavelength of the subsurface temperature waves were predicted and found to be in good agreement with the field measurements.

The influence of the initial temperature turned out to be not negligible especially at a great depth and when the time elapsed is not long enough. A practical and accurate method of estimating the initial temperature distribution within the system is warranted. Currently, a study is under way by the authors to develop a method for estimating the initial temperature distribution based the measured surface temperature history. In this paper, only the initial temperature uniform throughout the entire depth has been considered. However, to make the model more capable, it must be able to accommodate more general initial temperature distributions.

The only material parameter that has been involved in our heat conduction analysis was the thermal diffusivity of the medium (asphalt concrete), and we have used a value of α recommended in the literature and the results were fairly consistent with the field measurements. A marginal improvement in theoretical predictions was observed by trying values of α different from that recommended in the literature. A value of α obtained from an actual measurement may have to be used if the medium is of special design.

Finally, the model is based on the assumption of a homogeneous medium. In reality, many engineering problems are associated with an inhomogeneous medium. For instance, a typical pavement system consists of two or more layers with different thermo-mechanical properties. Our study has been restricted to the prediction of temperatures within the pavement surface layer, and the homogeneity assumption did not seem to cause a serious error. However, if one desires to predict the temperature of the underlying base or subgrade layers, the inhomogeneous thermal properties of each constituent layer must be considered.

Appendix L Derivation of Equation (33) from Equation (32):

In deriving (33) from (32), the following property of an integral in which a step function is included as part of its integrand was used:

$$\int_{t_0}^t f(\tau)H(\tau - t_1)d\tau = \int_{t_1}^t f(\tau)d\tau \quad \text{for } t_0 < t_1 < t. \quad (\text{A1})$$

Equation (A1) is based on the definition of the Heaviside step function given by (31). The integrands $f(\tau)$ and $f(\tau)H(\tau - t_1)$ used in Equation (A1) are graphically illustrated in Fig. A1.

Now consider the argument of the first step function that appears in (32). The range of ξ that makes the argument positive may be obtained by solving an inequality as follows:

$$t - \frac{x^2}{4\alpha\eta^2} - t_i > 0 \Rightarrow \eta > \frac{x}{2\sqrt{\alpha(t-t_i)}} \quad \text{for } \eta > 0, x > 0, t > t_i. \quad (\text{A2})$$

The first half of (32) may now be reduced as follows:

$$\begin{aligned} T_2(x, t) &= \frac{2}{\sqrt{\pi}} \int_{\frac{x}{2\sqrt{\alpha}}}^{\infty} \sum_{i=1}^n \left[F_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) H(t - \frac{x^2}{4\alpha\eta^2} - t_i) \right] e^{-\eta^2} d\eta \\ &= \frac{2}{\sqrt{\pi}} \sum_{i=1}^n \left[\int_{\frac{x}{2\sqrt{\alpha}}}^{\infty} F_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) H(t - \frac{x^2}{4\alpha\eta^2} - t_i) e^{-\eta^2} d\eta \right] \\ &= \frac{2}{\sqrt{\pi}} \sum_{i=1}^n \left[\int_{\frac{x}{2\sqrt{\alpha(t-t_i)}}}^{\infty} F_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) e^{-\eta^2} d\eta \right] \end{aligned} \quad (\text{A3})$$

The second half of (32) may also be reduced similarly.

Appendix II. Derivation of Equation (34) from Equation (33):

We shall consider a typical term in (33) and show how it can be reduced to the corresponding term in (34). Let us consider a term

$$\frac{2}{\sqrt{\pi}} \int_{X_i}^{\infty} F_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) e^{-\eta^2} d\eta \quad \text{where } X_i = \frac{x}{2\sqrt{\alpha(t-t_i)}} \quad (\text{A4})$$

which can be written, after (29), as

$$\frac{2}{\sqrt{\pi}} \int_{X_i}^{\infty} \left[A_i + B_i \left(t - \frac{x^2}{4\alpha\eta^2} \right) \right] e^{-\eta^2} d\eta \quad (\text{A5})$$

or

$$(A_i + B_i t) \frac{2}{\sqrt{\pi}} \int_{X_i}^{\infty} e^{-\eta^2} d\eta - B_i \frac{x^2}{4\alpha} \frac{2}{\sqrt{\pi}} \int_{X_i}^{\infty} \frac{e^{-\eta^2}}{\eta^2} d\eta. \quad (\text{A6})$$

The first integral may be expressed in terms of the *complementary error function* defined by (36), and the second integral may similarly be simplified after being integrated by parts; thus (A6) becomes

$$(A_i + B_i t) \operatorname{erfc}(X_i) - B_i \frac{x^2}{4\alpha} \left(\frac{2}{\sqrt{\pi}} \frac{e^{-X_i^2}}{X_i} - 2 \operatorname{erfc}(X_i) \right) \quad (\text{A7})$$

or

$$(A_i + B_i t) \operatorname{erfc}(X_i) + 2B_i (t - t_i) \left(X_i^2 \operatorname{erfc}(X_i) - \frac{X_i}{\sqrt{\pi}} e^{-X_i^2} \right) \quad (\text{A8})$$

where X_i is as defined in (35). Other terms in (34) may also be derived similarly.

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Notations

The following symbols are used in this paper:

c = specific heat (per unit mass)

\underline{g} = temperature gradient vector

$G(x)$, $F(t)$, $F_1(t)$, $F_2(t)$ = prescribed scalar-valued functions

$H(t)$ = the Heaviside step function

k = thermal conductivity

P = period of the temperature wave

\underline{q} = heat flux vector

q_I = rate of internal heat generation per unit volume

S_1 = temperature-prescribed boundary

S_2 = heat flux-prescribed boundary

t = time

$T = T(\underline{x}, t)$ = temperature field as a function of \underline{x} and t

T_i = uniform initial temperature

T_0 = constant surface temperature or the mean surface temperature

ΔT = amplitude of the surface temperature wave

$$\dot{T} = \frac{DT}{Dt} = \frac{\partial T}{\partial t} + \frac{\partial T}{\partial \underline{x}} \cdot \frac{d\underline{x}}{dt}$$

$$\frac{\partial T}{\partial n} = \underline{n} \cdot \frac{\partial T}{\partial \underline{x}} \quad (\underline{n} \text{ is the unit outward normal vector})$$

v = propagation speed of the temperature wave

V = spatial domain of the problem

\underline{x} = spatial coordinates ($= x\underline{i} + y\underline{j} + z\underline{k}$ in Cartesian coordinates)

α = thermal diffusivity

β = phase angle

λ = wavelength

ρ = mass density

ρc = thermal capacity (per unit volume)

ω = angular frequency

∇ = *del* operator ($= \frac{\partial}{\partial x}\underline{i} + \frac{\partial}{\partial y}\underline{j} + \frac{\partial}{\partial z}\underline{k}$ in Cartesian coordinates)

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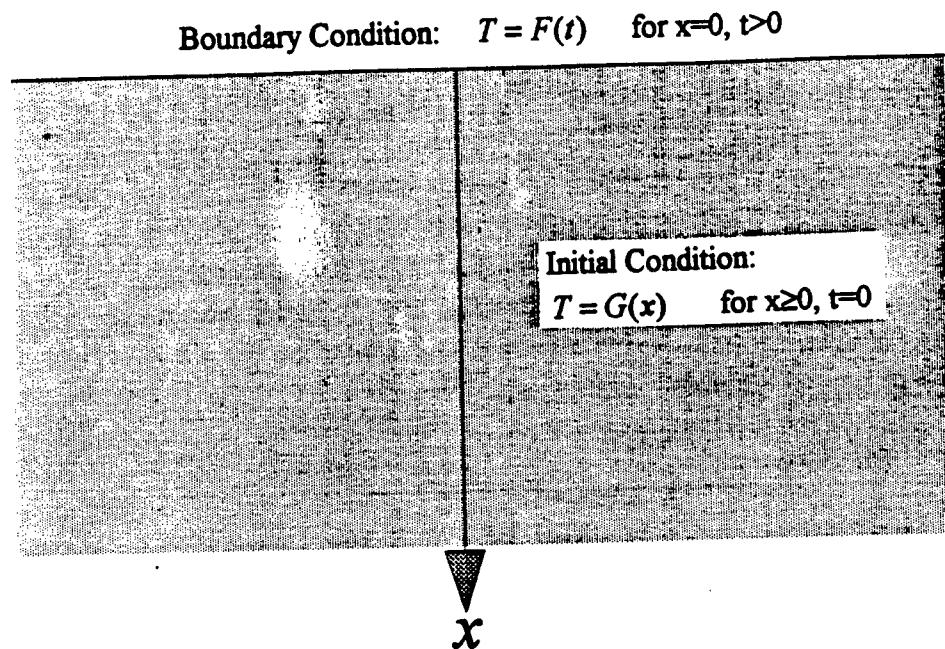
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Fig. A1. Graphical illustrations of $f(\tau)$ and $f(\tau)H(\tau - t_1)$ used in Equation (A1).



Governing Differential Equations: $\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$ for $x>0, t>0$

Fig. 1. One dimensional heat conduction in a semi-infinite solid.

$$F(t) = \sum_{i=1}^n F_i(t)[H(t-t_i) - H(t-t_{i+1})]$$

$F(t)$

where

$$F_i(t) = A_i + B_i t \quad \text{for } t_i \leq t < t_{i+1} \quad (i = 1, 2, \dots, n)$$

$$B_i = \frac{T_{i+1} - T_i}{t_{i+1} - t_i}, \quad A_i = T_i - B_i(t_i - t_i) \quad (t_{n+1}, T_{n+1})$$

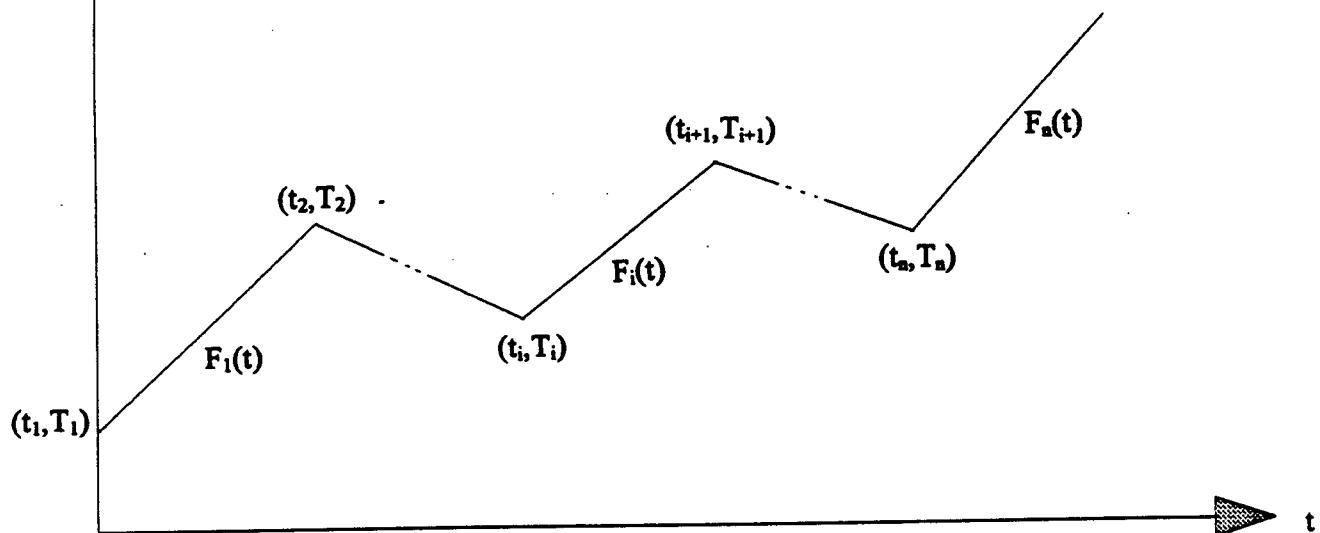


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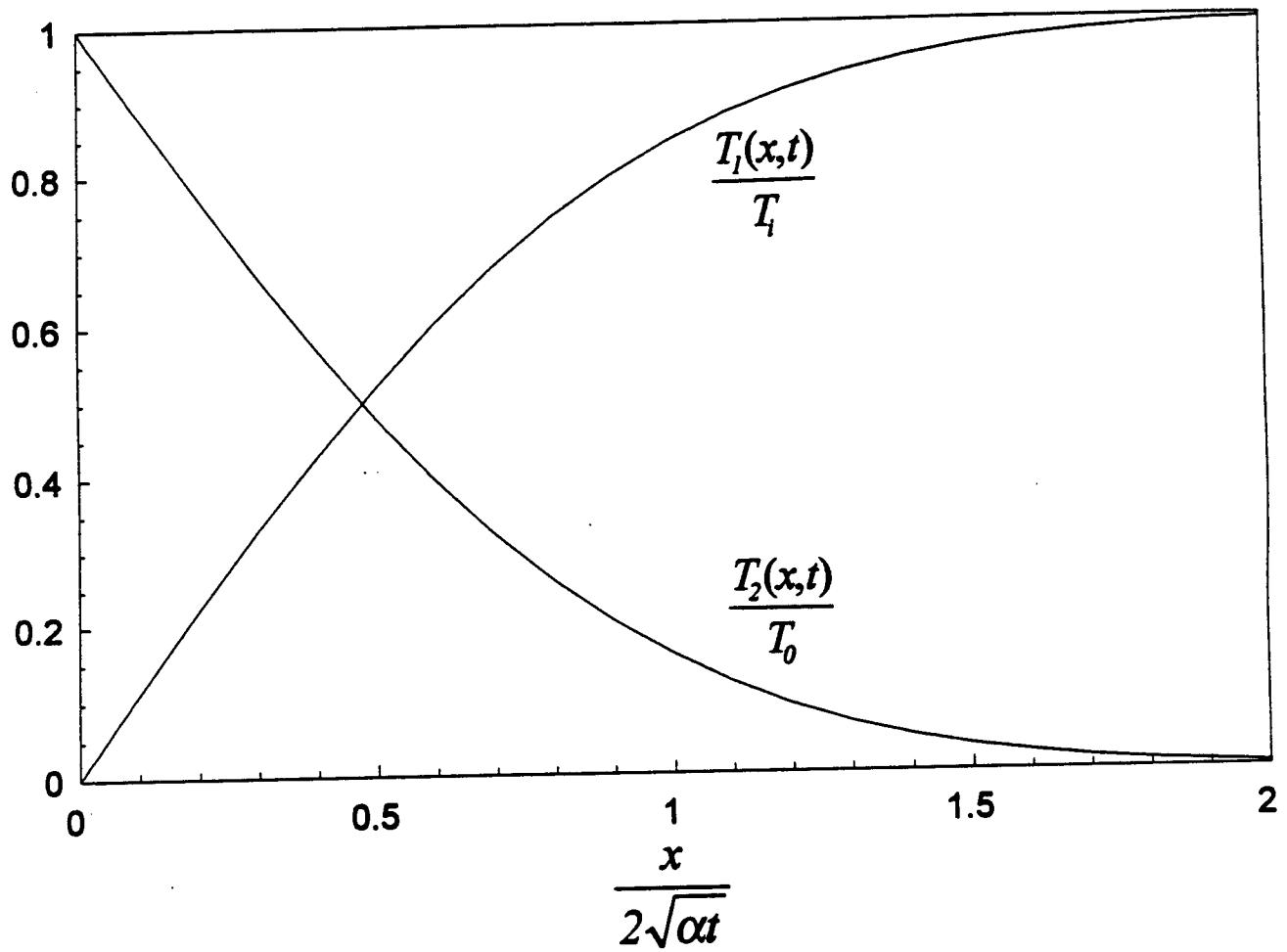


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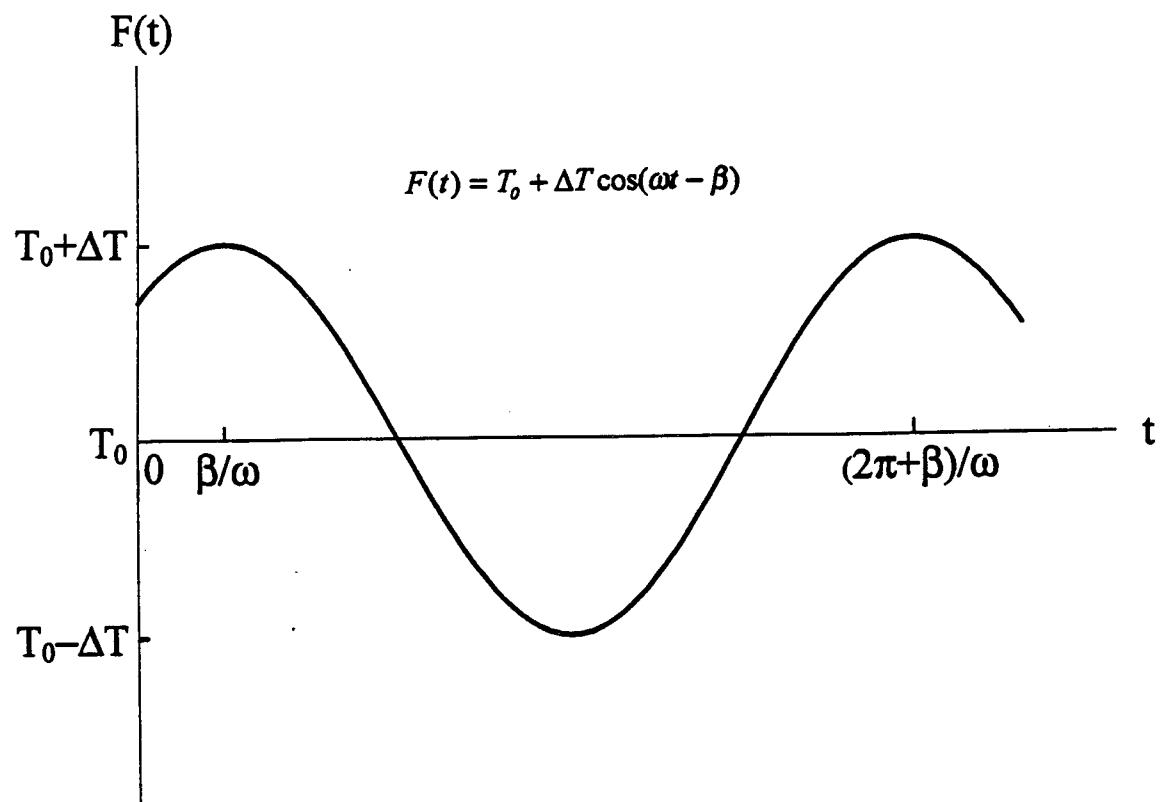


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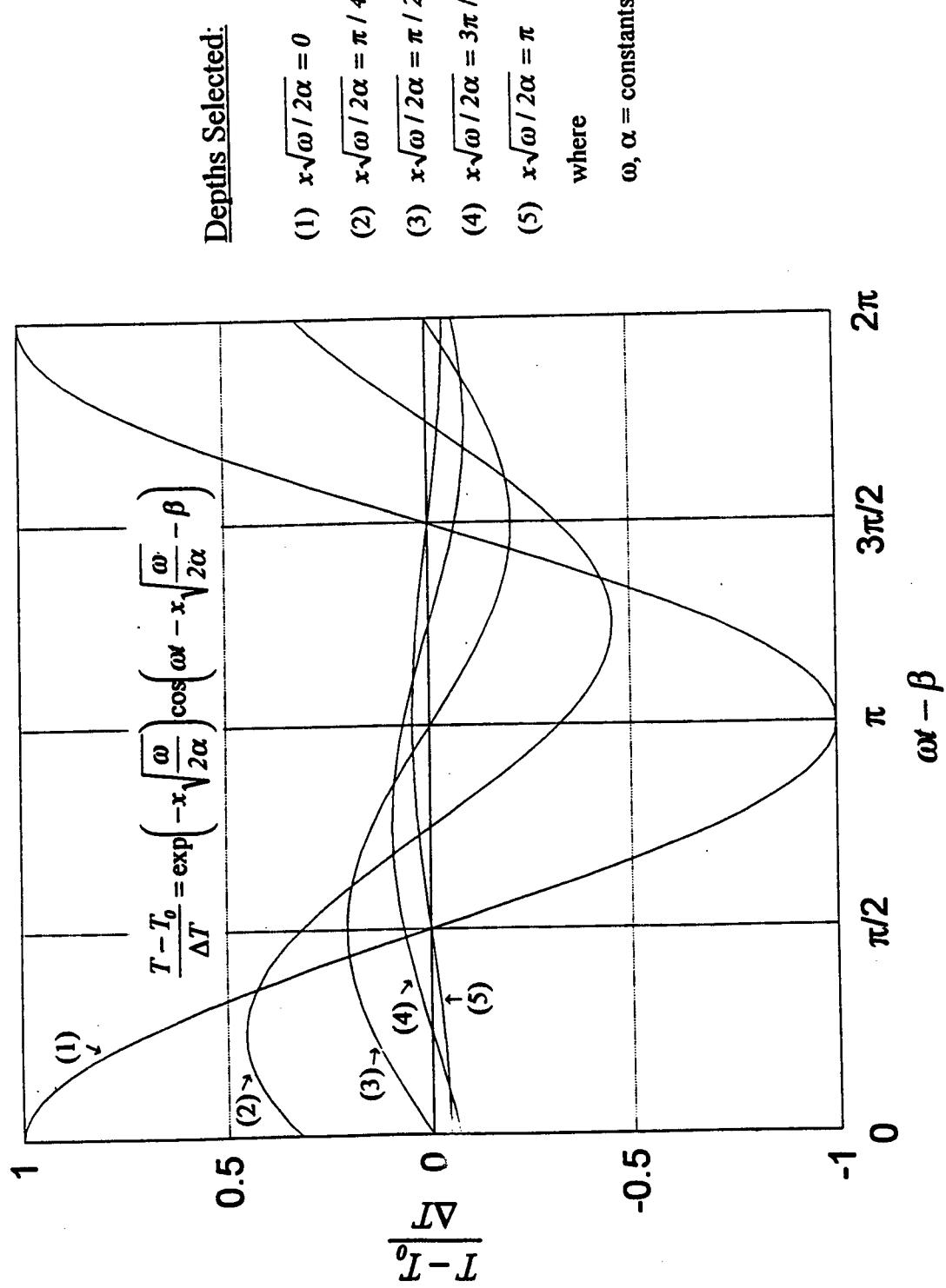


Fig. 5. Steady-state temperature variation with time at selected depths in a semi-infinite solid with a harmonic surface temperature variation.

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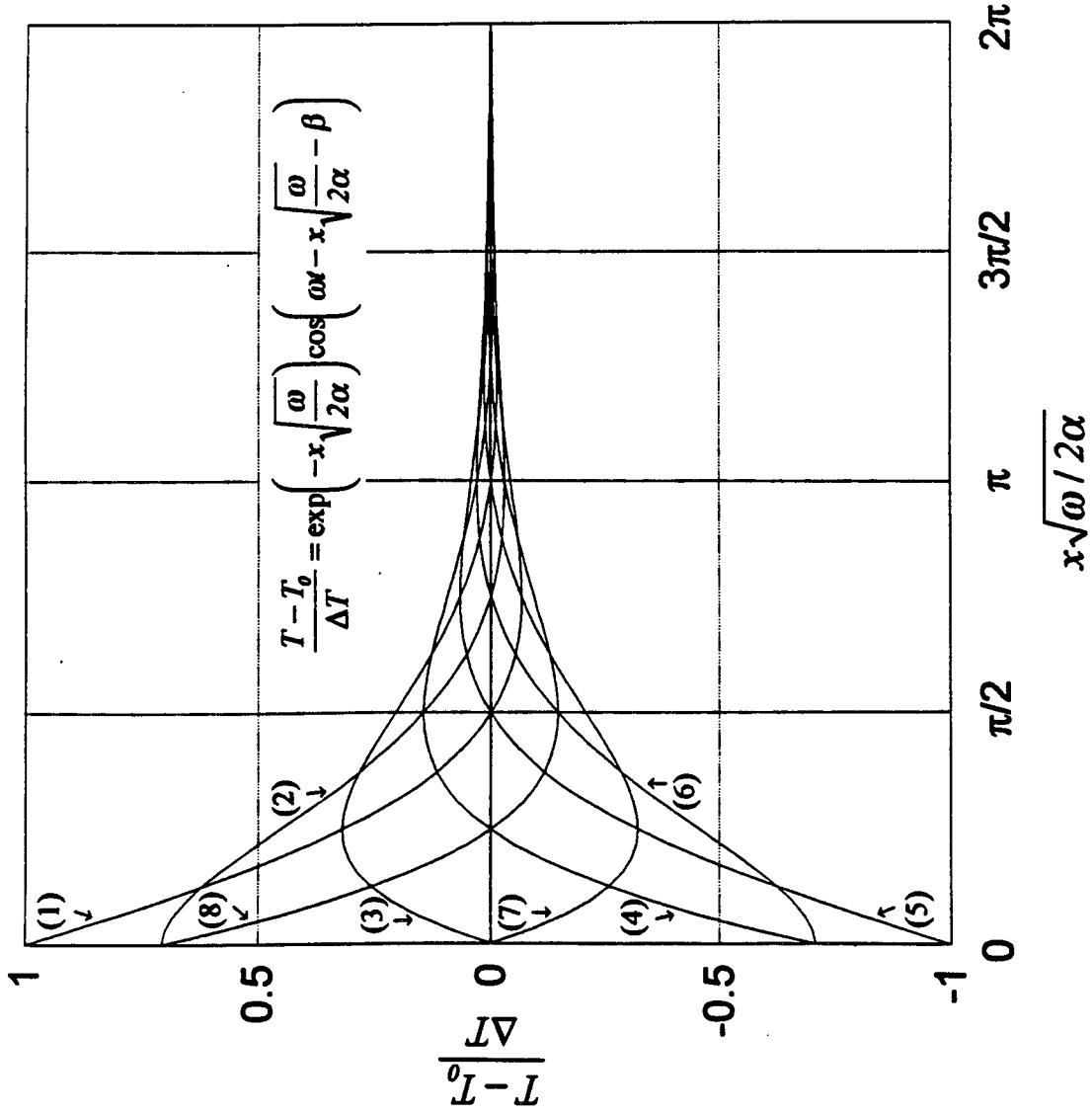


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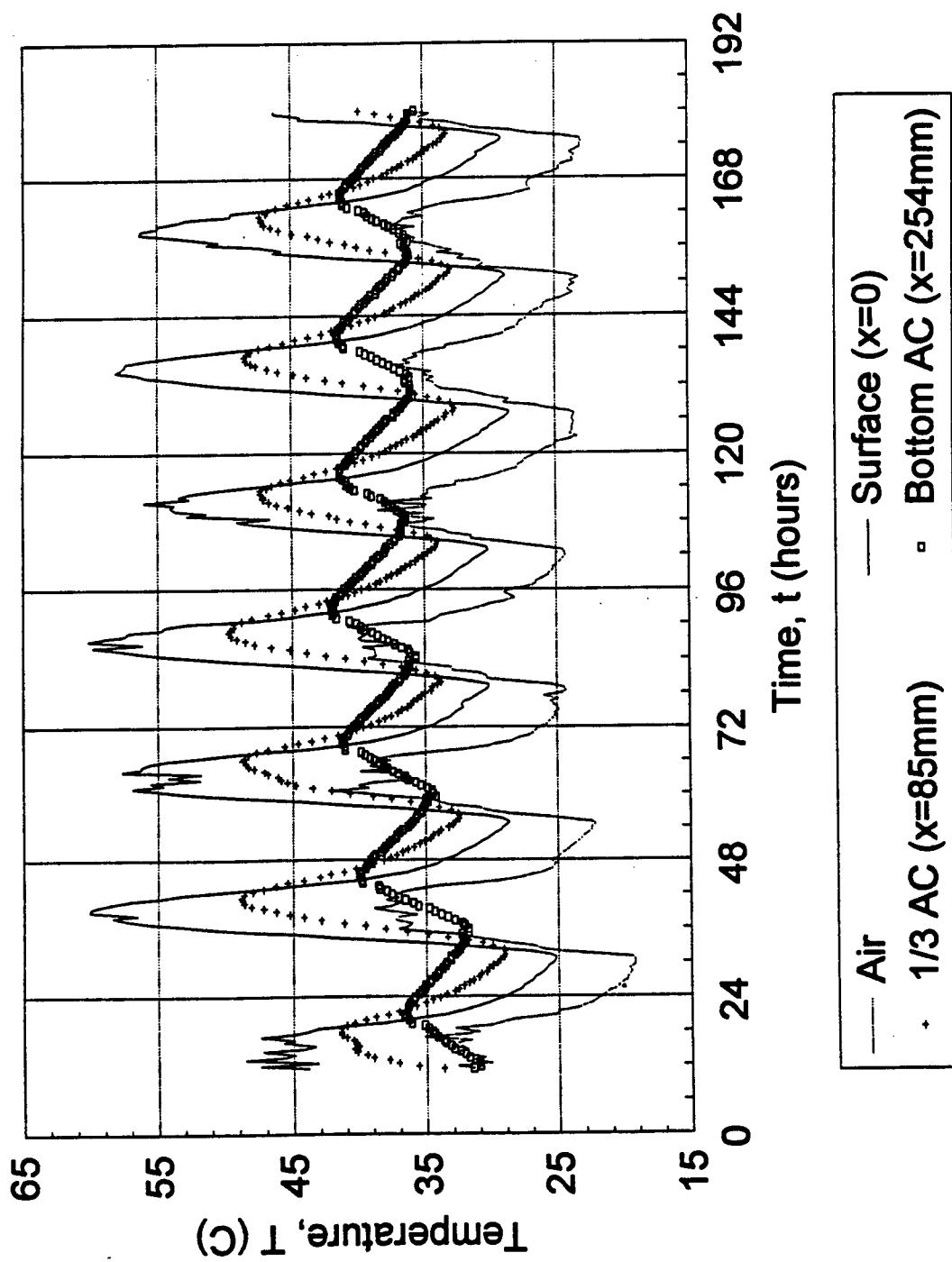


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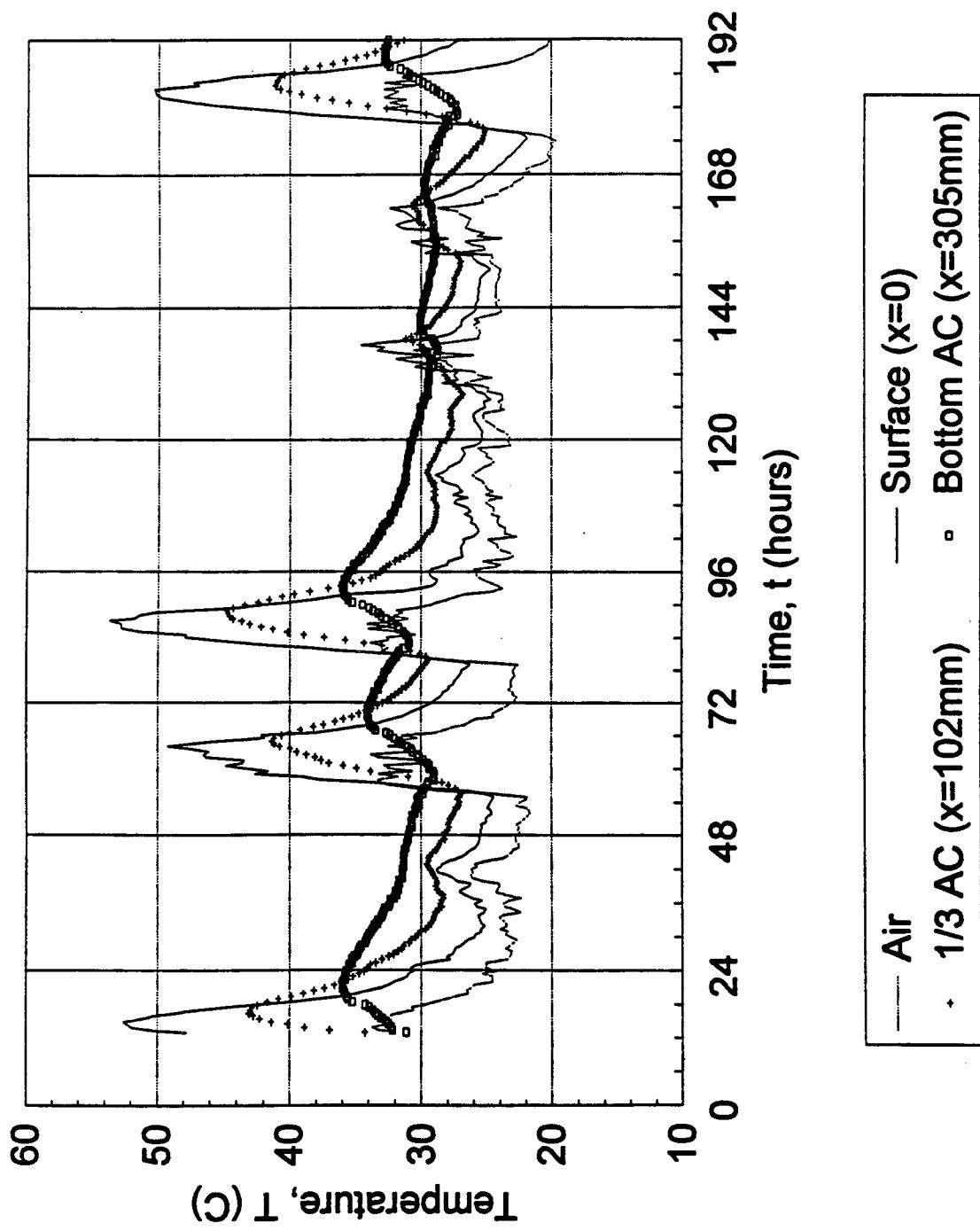


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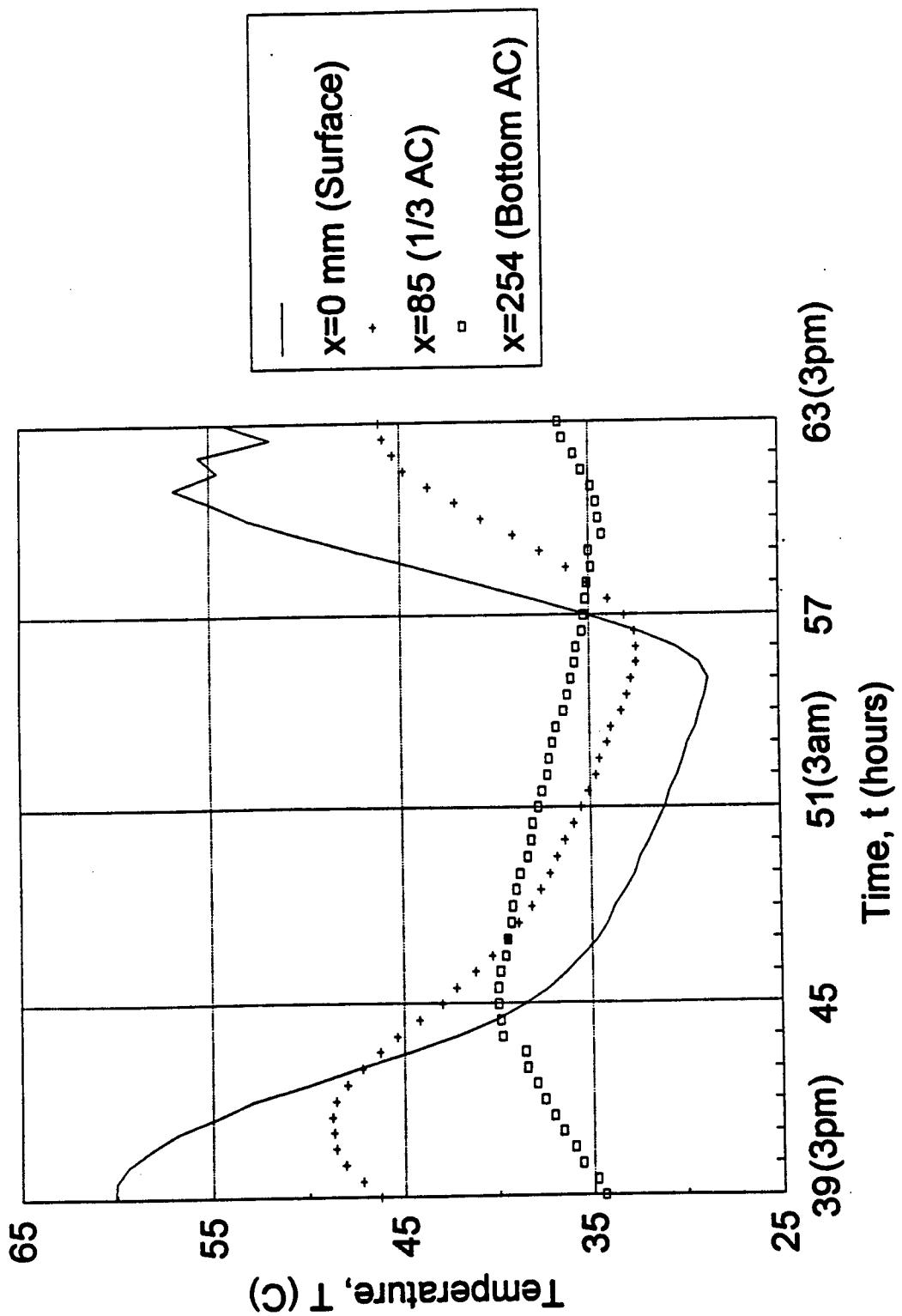


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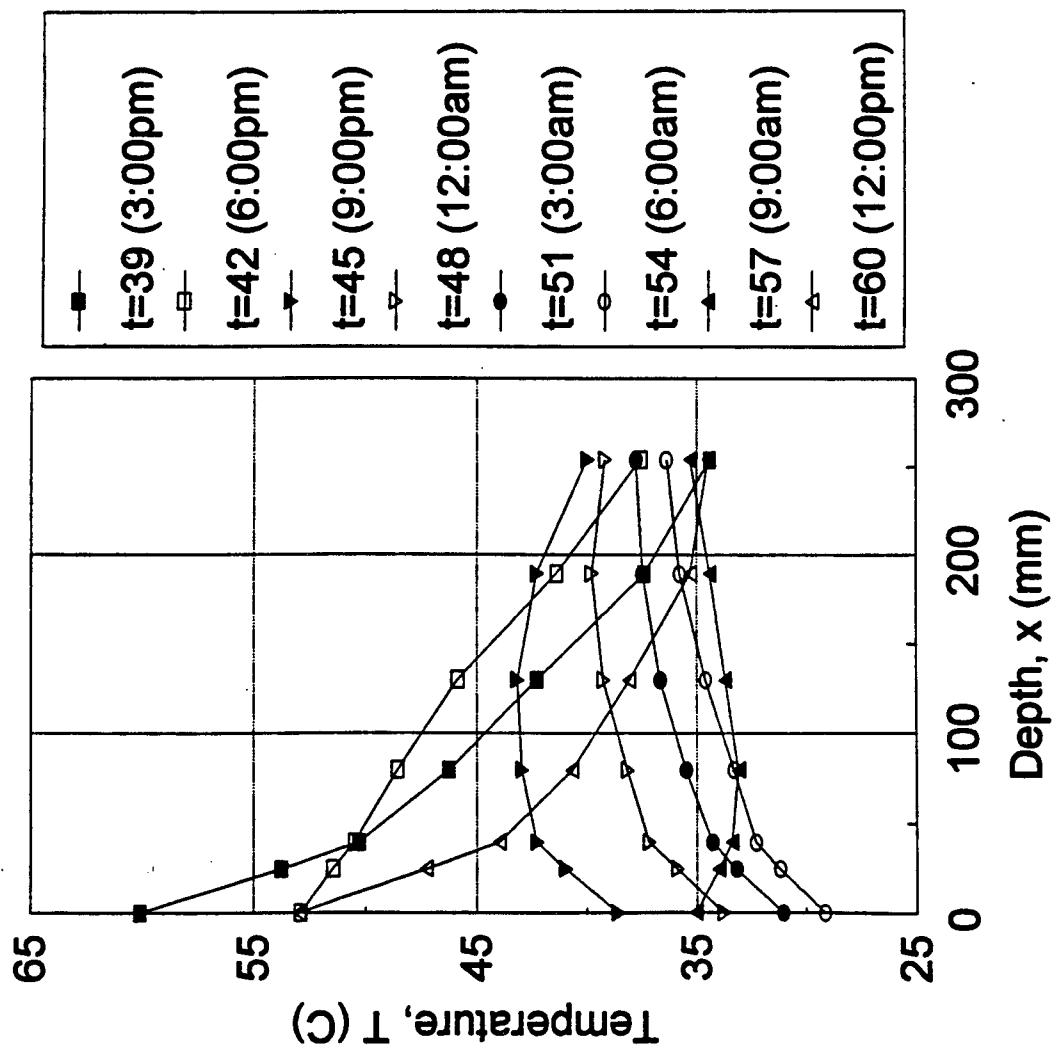


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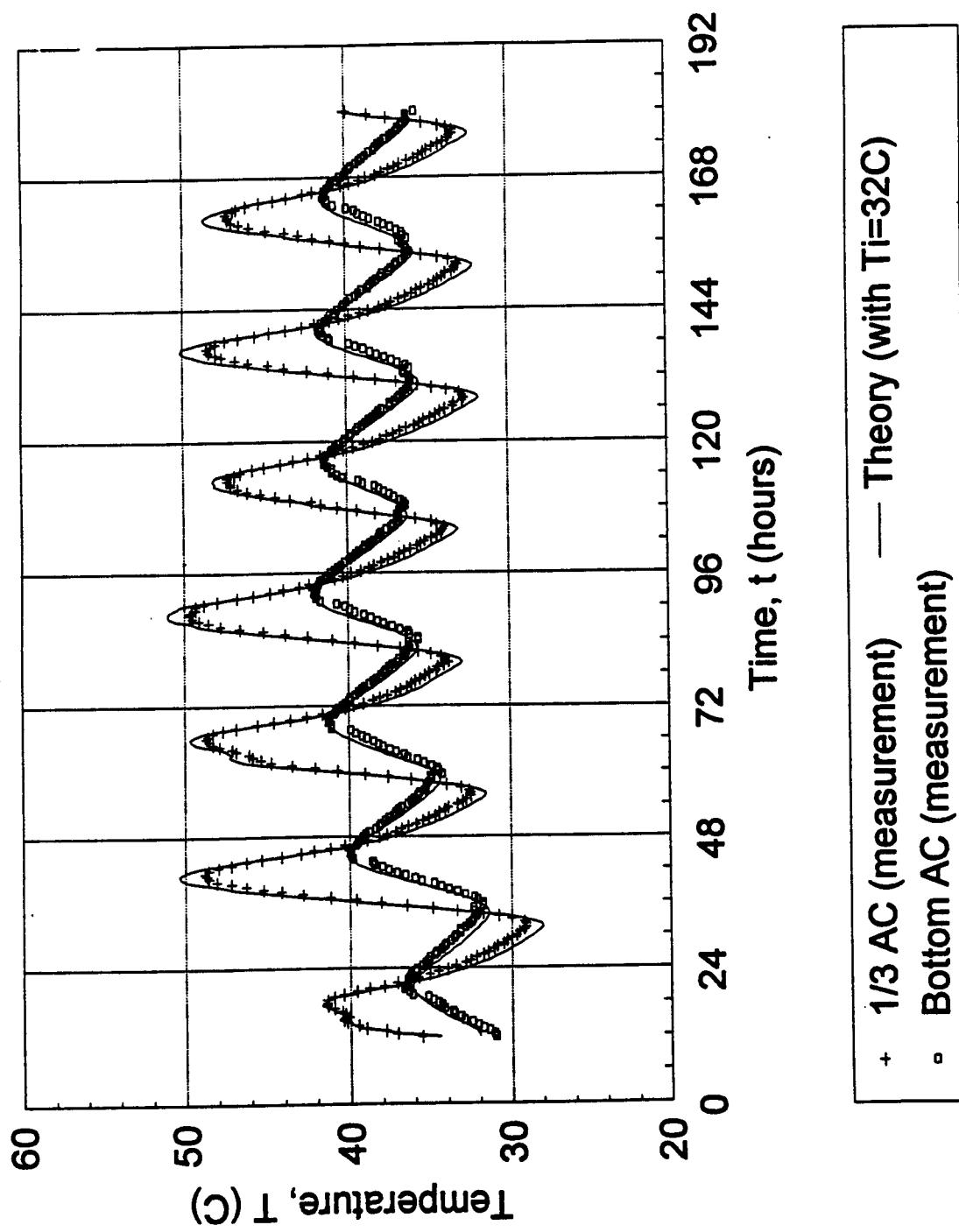


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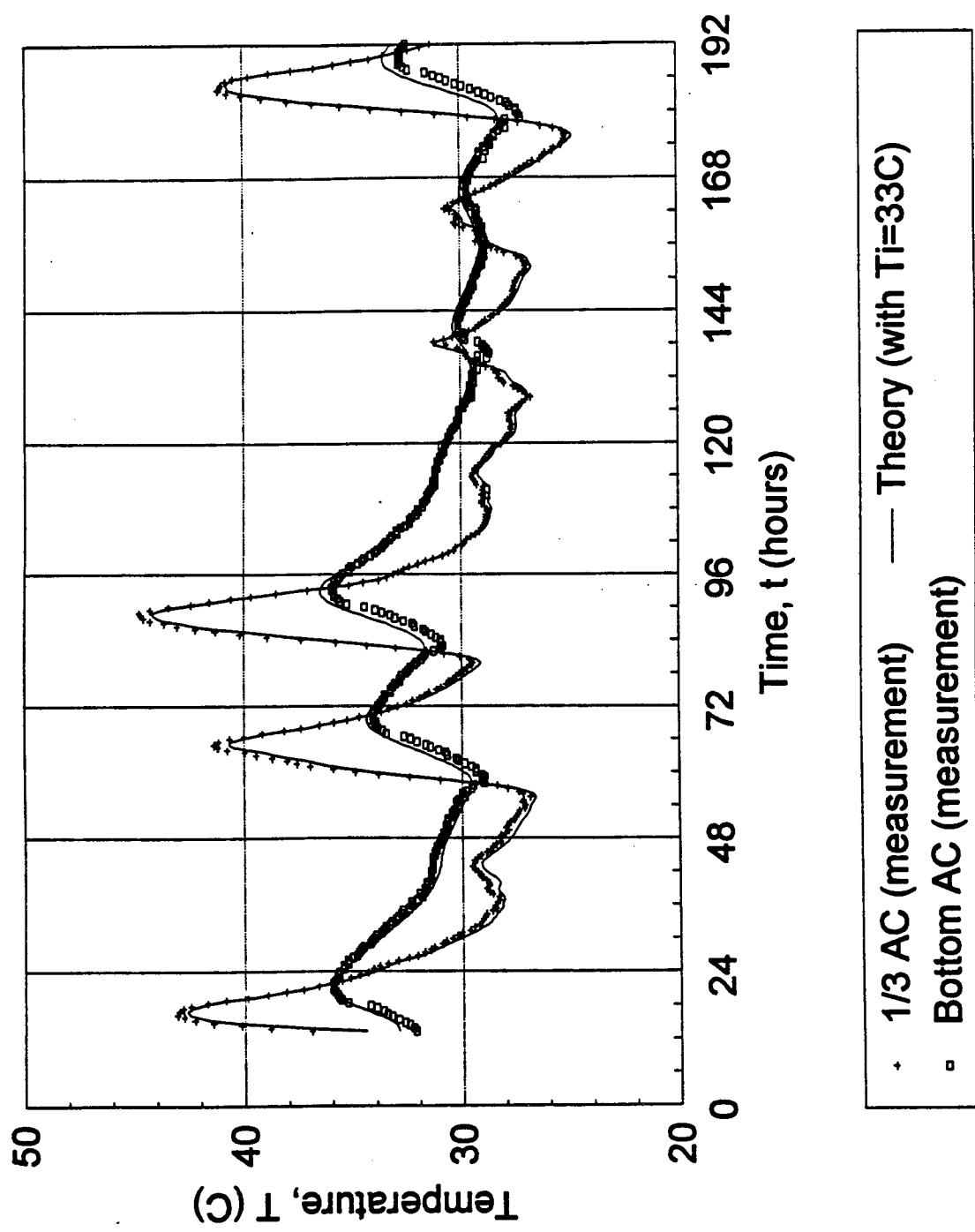


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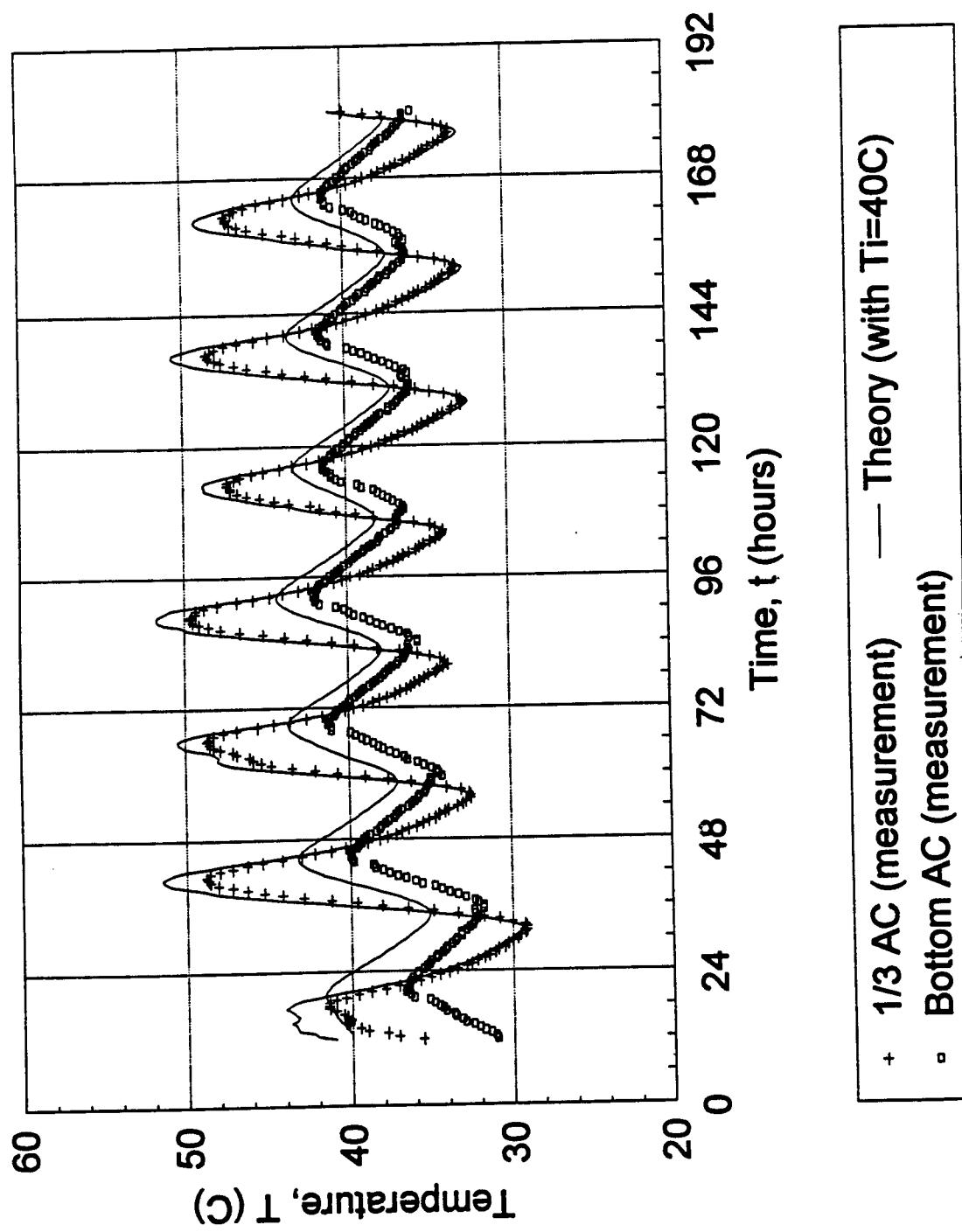


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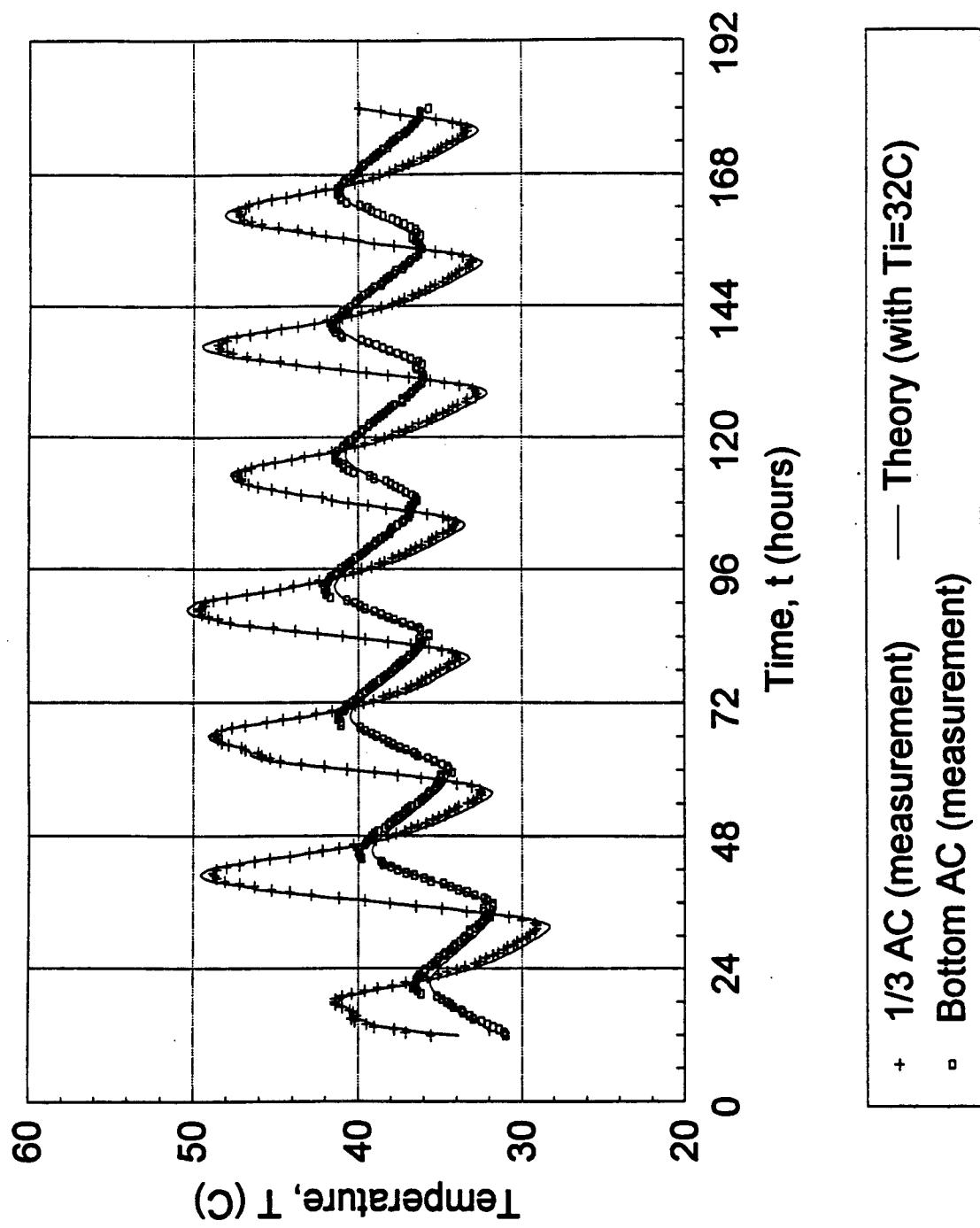


Fig. 14. Predicted and measured temperature variations with time at selected depths (Site A, $T_i = 32^\circ\text{C}$, $\alpha = 0.003 \text{ m}^2/\text{hr}$).

$$\text{A, } T_i = 32^\circ\text{C}, \alpha = 0.003 \text{ m}^2/\text{hr}.$$

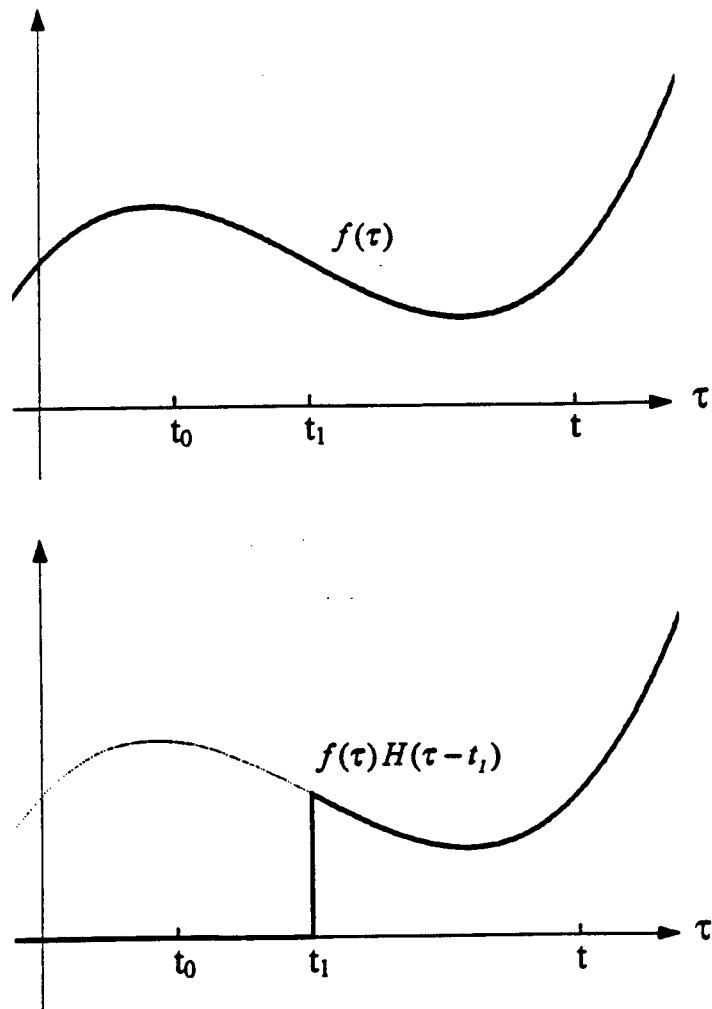


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APPENDIX B

ANALYSIS OF STRESSES AND DISPLACEMENTS IN LAYERED VISCOELASTIC SYSTEM WITH VARYING TEMPERATURE

1. Introduction

2. Layered Elastic System

3. Layered Viscoelastic System

4. Time-Temperature Superposition And Effects Of Temperatures

5. Illustrations: A Three-Layer Elastic/Viscoelastic Composite System

6. Concluding Remarks

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1. Introduction

The stresses and displacements in layered systems, such as layered soil deposits and pavement structures, have long been of particular interest to geotechnical and pavement engineers. Analysis of elastic multilayer systems have been pursued by many investigators in the past. Burmister (1943), using Love's stress function (Love 1927) and a Bessel function expansion of the load applied on a finite boundary surface, developed solutions for a two-layer system and then extended them to a three-layer system (Burmister 1945). Based on Burmister's analytical solutions, a number of authors produced extensive tabular and graphical summary of stresses and displacements in two- and three-layer systems for various combinations of geometrical and material parameters (e.g., Acum and Fox 1951, Jones 1962 , Peattie 1962, and Huang 1969).

When one or more layers in a multilayer system are composed of viscoelastic materials, the mechanical response of the system to applied excitation becomes time-dependent. In addition, the mechanical properties of most viscoelastic materials and the structural responses of viscoelastic systems depend strongly upon temperature.

The surface deflection of homogeneous viscoelastic halfspace to moving loads were investigated by Perloff and Moavenzadeh (1967). Subsequently, Chou and Larew (1969), Elliott and Moavenzadeh (1971), and Huang (1973) determined stresses and displacements in a viscoelastic two-, three-, and multi-layer system, respectively. Based on the work by Moavenzadeh et al. (1974), The Federal Highway Administration developed a computer code called VESYS (Kenis 1977) to predict the structural responses of layered viscoelastic systems and the integrity of flexible pavements. Many researchers have contributed to the improvement of VESYS system since it was first introduced. Huang

(1993) also introduced a computerized procedure for analysis of systems composed of linear elastic, nonlinear elastic, and/or viscoelastic layers. Most of these viscoelastic solutions were obtained utilizing the existing elastic solution procedure through the use of the elastic-viscoelastic correspondence principle and the linear superposition integral. However, temperature effects have not been emphasized in these analyses. Usually constant temperatures were accommodated through the time-temperature shift factor. but no general transient temperature histories have been *explicitly* incorporated.

In the present work, a procedure for the analysis of multilayer viscoelastic system subjected to general transient load and transient temperature histories is presented. First the responses to unit step load (unit response functions) will be obtained from the associated elastic solutions through the use of the elastic-viscoelastic correspondence principle. Then the responses to a general transient loading history will be obtained by the linear convolution integral of the unit response functions and the time-rate of the applied load. The unit response functions will be mathematically represented by a series of decaying exponentials (Prony series) which greatly facilitates the numerical procedures involved. The effects of constant temperatures are simply incorporated through the reduced time computed based on constant shift factors. Under a transient temperature history, the time-temperature shift factor and thus the reduced time are no longer constant, which adds complexity to the analysis procedure. However, it will be shown that the same analysis framework developed for isothermal conditions can still be used for transient temperature conditions when one appropriately defines an *effective* shift factor. The effective shift factor will account for the effects of the entire past history of temperature. It is assumed that the viscoelastic materials involved are thermorheologically simple and the

usual time-temperature superposition principle applies. For the illustration purposes, a three-layer elastic/viscoelastic composite system composed of a viscoelastic surface layer and two underlying elastic layers, simulating a typical flexible (or asphalt concrete) pavement system, is investigated. Different combinations of loading and temperature histories are considered.

2. Layered Elastic System

Fig. 1 shows a semi-infinite n-layer elastic system subjected to uniformly distributed load on a circular area. The geometry of structure and the configuration of loading leads to an axisymmetric problem that can be best described in cylindrical coordinates. The nonzero field variables in bodies of revolution (axisymmetric bodies) under axisymmetric loading are listed in Fig. 1. The symbols used will be identified later. The nonzero components of the stress tensor in an axisymmetric state of stress are illustrated in Fig. 2. Stress components equal in magnitude and opposite in direction also exist on each opposite face of the element. Each layer is assumed to be infinite in extent in the horizontal direction but of finite thickness (h_i), whereas the bottom layer (the n-th layer) is infinite in both horizontal and vertical directions. The material in each layer is assumed to be homogeneous, isotropic, and linearly elastic and is characterized by its Young's modulus (E_i) (which is reciprocal of uniaxial compliance, D_i) and Poisson's ratio (ν_i). The boundary conditions are such that the surface is free of normal and shear stresses except the normal stress under the circular loaded area with radius of a is equal to $-q(t)$. The equilibrium and continuity conditions at $n-1$ interfaces require equalities of normal stresses, shear stresses, vertical displacements, and horizontal displacements across the

interfaces. If the interface is frictionless, the equalities of shear stresses and radial displacements across the interface are to be replaced by vanishments of shear stresses both above and beneath the interfaces.

Following Love (1927), the stresses and displacements in an axisymmetric elastic system under axisymmetric loading are given by

$$\sigma_{rr} = \frac{\partial}{\partial z} \left[\nu \nabla^2 \phi - \frac{\partial^2 \phi}{\partial r^2} \right] \quad (1)$$

$$\sigma_{\theta\theta} = \frac{\partial}{\partial z} \left[\nu \nabla^2 \phi - \frac{1}{r} \frac{\partial \phi}{\partial r} \right] \quad (2)$$

$$\sigma_{zz} = \frac{\partial}{\partial z} \left[(2 - \nu) \nabla^2 \phi - \frac{\partial^2 \phi}{\partial z^2} \right] \quad (3)$$

$$\tau_{rz} = \frac{\partial}{\partial r} \left[(1 - \nu) \nabla^2 \phi - \frac{\partial^2 \phi}{\partial z^2} \right] \quad (4)$$

$$u = -\frac{1 + \nu}{E} \left[\frac{\partial^2 \phi}{\partial r \partial z} \right] \quad (5)$$

$$w = \frac{1 + \nu}{E} \left[2(1 - \nu) \nabla^2 \phi - \frac{\partial^2 \phi}{\partial z^2} \right] \quad (6)$$

provided that the stress function ϕ satisfies the biharmonic equation

$$\nabla^4 \phi = 0 \quad (7)$$

where, for axisymmetric problems,

$$\nabla^4 = \left(\frac{\partial^2}{\partial r^2} + \frac{1}{r} \frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2} \right) \left(\frac{\partial^2}{\partial r^2} + \frac{1}{r} \frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2} \right) \quad (8)$$

and r , θ , and z are the cylindrical coordinates for radial, circumferential, and vertical directions, respectively. The symbols u and w in (5) and (6) denote horizontal and vertical displacement components, respectively. Strains may be obtained by taking appropriate derivatives of displacements (5) and (6) or by substituting stresses (1)-(4) into the linear elastic stress-strain relations. The problem reduces to finding the single scalar function ϕ that satisfies (7) and the following boundary conditions:

surface boundary conditions:

$$(\sigma_z)_1 = \begin{cases} -q & \text{for } |r| < a \text{ and } z = 0 \\ 0 & \text{for } |r| > a \text{ and } z = 0 \end{cases} \quad (9)$$

and

$$(\tau_r)_1 = 0 \quad \text{for } z = 0. \quad (10)$$

interface boundary conditions:

$$(\sigma_z)_i = (\sigma_z)_{i+1}, \quad (11)$$

$$(\tau_r)_i = (\tau_r)_{i+1}, \quad (12)$$

$$(u)_i = (u)_{i+1}, \quad (13)$$

and

$$(w)_i = (w)_{i+1} \quad (14)$$

where the subscript $i = 1, 2, \dots n-1$ denotes the sequence of layers from top to bottom. As the stresses and displacements must vanish at an infinite depth, ϕ must vanish there, i.e.,

boundary conditions at infinite depth:

$$(\phi)_n = 0 \quad \text{as } z \rightarrow \infty. \quad (15)$$

The conditions (11)-(14) are for fully bonded interfaces; however, for frictionless interfaces, the second and the third conditions (12) and (13) must be replaced by $(\tau_{zz})_i = 0$ and $(\tau_{rz})_{i+1} = 0$. Love (1927) presented $\exp(\pm kz)J_0(kr)$, $\exp(\pm kz)rd/drJ_0(kr)$, $\exp(\pm kz)zJ_0(kr)$, and $(r^2+z^2)^{n+1/2}\partial/\partial z^n(r^2+z^2)^{-1/2}$ ($n = 0, 1, 2, \dots$) and their products with (r^2+z^2) as the base solutions to (7). Burmister (1943, 1945) took the following form of ϕ for each layer with four unknown constants:

$$(\phi)_i = J_0(mr)[A_i e^{mx} - B_i e^{-mx} + C_i z e^{mx} - D_i z e^{-mx}] \quad (16)$$

where $J_0()$ is a Bessel function of the first kind and order zero, m is a positive constant, and $i = 1, 2, \dots, n$ denotes the layer number. Four constants of integration are normally required to solve a fourth-order differential equation. For an n -layer system, the total number of unknown constants is $4n$, which must be determined by two surface boundary conditions, $4(n-1)$ interface boundary conditions, and two infinite-depth boundary conditions; substituting (16) into the infinite-depth boundary condition (15) yields two conditions, $A_n = C_n = 0$.

It turns out that the boundary condition (9) is difficult to impose without further treatment because σ_{zz} in the top layer ($i=1$), from (3) and (16), contains a common factor $-mJ_0(mr)$; i.e.,

$$(\sigma_{zz})_1 = -mJ_0(mr)[A_1 m^2 + B_1 m^2 - C_1 m(1-2v) + D_1 m(1-2v)] \quad (17)$$

where subscript 1 denotes the top layer. Burmister (1943) solved the problem first for the loading condition $(\sigma_{zz})_1 = -mJ_0(mr)$ on $z = 0$, and then obtained the response to the actual loading condition $(\sigma_{zz})_1 = -q$ on $|r| < a$ and $z = 0$ by representing the actual

loading condition by a Bessel function expansion and carrying out a numerical integration.

The Bessel function expansion of load q uniformly distributed over a circular area of radius a is given by

$$q(r) = \int_0^\infty m J_0(mr) \hat{q}(m) dm \quad (18)$$

where

$$\hat{q}(m) = \int_0^\infty r J_0(mr) q(r) dr \quad (19)$$

is *Hankel transform* of $q(r)$ (e.g., Greenberg 1978). Since q is constant over $|r| < a$, (19) reduces to

$$\hat{q}(m) = q \int_0^a r J_0(mr) dr = qa \frac{J_1(ma)}{m} \quad (20)$$

where $J_1()$ is the Bessel function of the first kind and order one. Substituting (20) into (18)

$$q(r) = qa \int_0^\infty m J_0(mr) \frac{J_1(ma)}{m} dm. \quad (21)$$

Therefore, if R^* is the response due to load $m J_0(mr)$ and R is that due to load q , then

$$R = qa \int_0^\infty R^*(m) \frac{J_1(ma)}{m} dm. \quad (22)$$

The solution R^* for given m is obtained by first determining the $4n$ constants of integration A_i, B_i, C_i , and D_i ($i = 1, 2, \dots, n$) from the $4n$ boundary conditions, and then substituting these constants into (16) and (1) - (6). The true solution R is then obtained by (22). The integration in (22) can be carried out numerically with appropriate intervals on m .

3. Layered Viscoelastic System

Fig. 3 shows a semi-infinite n-layer viscoelastic system subjected to uniformly distributed load on a circular area. The material in each layer is assumed to be homogeneous, isotropic, and linearly viscoelastic and is characterized by its uniaxial creep compliance and Poisson's ratio. Here, the creep compliance $D(t)$ rather than the relaxation modulus $E(t)$ is used since the boundary conditions are specified in terms of tractions rather than displacements. For elasticity problems, however, either E or D ($= 1/E$) may be used for both type of boundary conditions with equal facility. Poisson's ratios denoted in Fig. 3 are those obtained from creep tests. The geometry, loading and interface conditions for the viscoelastic layered problem are the same as those for the elastic n-layer system introduced earlier (Fig. 1). However, a general time-varying load q will be considered. For an elastic system the current response depends only on the current value of q , and therefore no particular feature is added when time-varying load is considered. For a viscoelastic system, the current response depends not only on the current value but also on the entire past history of the load q . Both constant and transient loads will be considered in this study. The mechanical properties of elastic materials are not sensitive to moderate temperature changes but the properties of viscoelastic materials are much dependent on temperature. Typically the creep or relaxation process for most polymers and polymeric composites is accelerated as temperature rises. The effects of temperature on the material properties (and thus mechanical responses) of the viscoelastic system will be incorporated through the well-known *time-temperature superposition* principle. Both constant and transient temperature histories will be considered. Thermal expansion (or contraction) may be taken into account by including thermal strain (or stress) terms in the stress-strain

equations; however, the thermal expansion effects will not be considered in this study for simplicity.

a. The Elastic-Viscoelastic Correspondence Principle

It has been well known that there exists an important correspondence between the set of mathematical conditions (field equations and boundary conditions) for a linear elastic boundary value problem and the set of integral-transformed (typically Laplace transformed) mathematical conditions for a linear viscoelastic boundary value problem. More specifically, if the given viscoelastic boundary value problem is described in terms of field variables, $u_i(t)$, $\varepsilon_{ij}(t)$, $\sigma_{ij}(t)$, and material properties, $D(t)$ and $v(t)$ and if the corresponding elastic problem is described in terms of u_i , ε_{ij} , σ_{ij} and constant material properties D and v , then the set of mathematical conditions that describes the elastic problem can also be used to describe the corresponding viscoelastic problem if u_i , ε_{ij} , σ_{ij} , D , and v in the conditions are replaced by \bar{u}_i , $\bar{\varepsilon}_{ij}$, $\bar{\sigma}_{ij}$, \tilde{D} , and \tilde{v} where a bar over a variable designates its Laplace transform and a tilde designates its s-multiplied Laplace transform, i.e.,

$$\tilde{f}(s) = \int_0^\infty f(t)e^{-st} dt \quad (23)$$

and $\tilde{f} \equiv sf$. Note that \tilde{f} and f have the same dimension and $\tilde{f} = f$ when f is constant. The stress function ϕ introduced in the preceding section depends upon the loading, geometry, and material properties of the system and will be a function of time for a viscoelastic system; therefore, ϕ also needs to be changed to $\tilde{\phi}$ according to the correspondence principle. For example, the equation for vertical displacement (6) for elastic system can be

converted to the following Laplace-transformed equation for the corresponding viscoelastic system:

$$\bar{w} = (1 + \tilde{\nu}) \tilde{D} \left[2(1 - \tilde{\nu}) \nabla^2 \bar{\phi} - \frac{\partial^2 \bar{\phi}}{\partial z^2} \right]. \quad (24)$$

The factor $1/E$ in (6) was replaced by D before the equation was Laplace-transformed. Based on this correspondence, the Laplace-transformed viscoelastic solutions are obtained directly from the solutions of the corresponding elastic problem by replacing D , ν , ϕ with \tilde{D} , $\tilde{\nu}$, and $\bar{\phi}$, respectively. The final time-domain viscoelastic solution will be obtained upon inverting the transformed solution. An entirely similar procedure follows from the use of the Fourier transform. Read (1950) used the Fourier transform and Sips (1951), Lee (1955), and Biot (1958) used the Laplace transform to illustrate the elastic-viscoelastic correspondence principle.

The correspondence principle may be applied to solve the layered viscoelastic problem. According to the principle, the governing equations and the boundary conditions (1) - (7) and (9) - (15) for the elastic system may be converted to those for the viscoelastic system by simply replacing all the field variables with their Laplace transforms and the material constants D and ν with \tilde{D} and $\tilde{\nu}$, respectively. Now the true viscoelastic solutions should be evaluated by inverting the Laplace-transformed viscoelastic solutions that are obtained from the corresponding elastic solutions. However, in view of the forms of the equations (1) - (6), it is believed that analytical inversions would be very difficult and numerical inversions would not be feasible, either, because of the complexity of the form $\bar{\phi}$; $\bar{\phi}$ is a function of \tilde{D} 's and $\tilde{\nu}$'s of different layers, loading and geometry. Therefore the Laplace-transform based correspondence principle would no longer be

considered in this study, instead, as an alternative approach, the *linear superposition integral* method, which will be discussed in the next section, will be adopted. Even though the method does not deal with each individual material function explicitly as does the Laplace-transform based correspondence principle, it still accounts for all the viscoelastic hereditary effects of the system as a whole through appropriate kernel functions (or *unit response functions* which will be defined later).

b. Linear Superposition Integral and Unit Response Functions

For linear viscoelastic media, the response can be expressed by a convolution integral of the unit response function and the input rate as follows:

$$R(t) = \int_0^t R_H(t-\tau) \frac{dI(\tau)}{d\tau} d\tau \quad (25)$$

where $R(t)$ is the response, $I(t)$ is the input, and $R = I = 0$ for $t < 0$. The function $R_H(t)$ in (25) is commonly referred to as the *unit response function* as it signifies the response of the system to the unit step input; i.e., from (25)

$$R(t) \equiv R_H(t) \quad \text{for } I(t) = H(t) \quad (26)$$

where $H(t)$ is the Heaviside step function, i.e., $H(t) = 1$ for $t > 0$ and $H(t) = 0$ for $t < 0$.

For a linear elastic medium, R_H is constant and (25) reduces to

$$R^*(t) = R_H^* I(t) \quad (27)$$

which further reduces to

$$R^* = R_H^* \quad \text{for } I(t) = H(t) \quad (28)$$

where the superscript e denotes the corresponding elastic system.

In view of (26) and (28), there exists a useful correspondence between the viscoelastic unit response and the associated elastic unit response. This correspondence is

crucial in obtaining the viscoelastic unit response function from the associated elastic solution. The viscoelastic unit response $R_H(t)$ in (26) is a function of time-dependent viscoelastic material properties, say, $D(t)$ and $v(t)$, as well as geometrical parameters; whereas the elastic unit response R_H^e in (28) is a function of constant elastic material properties, say D^e and v^e as well as geometrical parameters. Therefore, if the viscoelastic system and the corresponding elastic system have the same geometry and are both subjected to the unit step input, the viscoelastic response at a particular time, say $t = t_1$, can be obtained from the corresponding unit response of the elastic system having the viscoelastic material properties evaluated at $t = t_1$; i.e.,

$$R_H(t_1) = R_H^e \Big|_{D^e = D(t_1) \text{ and } v^e = v(t_1)}. \quad (29)$$

Equation (29) is good for traction-specified boundary value problems. For displacement-specified problems, (29) still applies if the condition $D^e = D(t_1)$ and $v^e = v(t_1)$ is replaced with $E^e = E(t_1)$ and $\nu^e = \nu_r(t_1)$ where $\nu_r(t)$ is the Poisson's ratio for the viscoelastic material obtained from a relaxation test whereas $v(t)$ is the one from a creep test. Again, it is to be noted that $D^e = 1/E^e$ but $D(t_1) \neq 1/E(t_1)$ and $v(t_1) \neq \nu_r(t_1)$ in general. The same procedure may be repeated for a number of other times until the desired $R_H(t)$ is obtained either in a discrete form or in an analytical form through an appropriate curve fitting.

Equation (25) may be generalized to multi-responses and multi-inputs assuming the system is linear with respect to all of these,

$$R_i(t) = \int_0^t R_{Hij} (t - \tau) \frac{dI_j(\tau)}{d\tau} d\tau \quad (30)$$

where R_i ($i = 1, 2, \dots, m$) and I_j ($j = 1, 2, \dots, n$) are the sets of responses and inputs, respectively, and the usual summation convention is followed wherein repeated indices

imply summation over their range. The unit response functions $R_{Hij}(t)$ is obtained by measuring $R_i(t)$ when all inputs are zero except for one $I_j(t) = H(t)$, and the responses $R_i(t)$ to general time-dependent inputs can be calculated according to (30). Equation (25) deals with different histories of the same physical input but (30) accommodates the combined action of different histories of different physical inputs. The convolution integrals (25) and (30) apply not only to the stress-strain relations of linear viscoelastic materials but also to the structural analysis of linear viscoelastic bodies, and are often called *Duhamel's integral* or *Boltzmann superposition integral*. In a stress-strain equation $R_{Hij}(t)$ are functions of material properties only, but in a structural analysis problem $R_{Hij}(t)$ are functions of both material and geometrical parameters of the system. For instance, (30) may be used to express the uniaxial stress-strain relationship for linear viscoelastic materials, with $m = n = 1$,

$$\sigma(t) = \int_0^t E(t-\tau) \frac{d\varepsilon(\tau)}{d\tau} d\tau \quad (31)$$

or

$$\varepsilon(t) = \int_0^t D(t-\tau) \frac{d\sigma(\tau)}{d\tau} d\tau \quad (32)$$

where $E(t)$ and $D(t)$ are the uniaxial relaxation modulus and the creep compliance, respectively. On the other hand, (30) may also be specialized to represent the force-displacement relationship for a uniaxial bar,

$$F(t) = \int_0^t K(t-\tau) \frac{du(\tau)}{d\tau} d\tau \quad (33)$$

or

$$u(t) = \int_0^t S(t-\tau) \frac{dF(\tau)}{d\tau} d\tau \quad (34)$$

where $K(t) = AE(t)/L$ is the uniaxial stiffness, $S(t) = LD(t)/A$ is the uniaxial flexibility, F , u , A , and L are axial force, axial displacement, cross-sectional area, and length of the bar, respectively. In most viscoelastic structural analysis problems, the geometry of the system is assumed to be time-independent and the time-dependence of the unit response functions $R_{Hij}(t)$ is solely from the time-dependence of the material properties.

c. Analysis of Viscoelastic Layered System

For the problem depicted in Fig. 3, a single input which is the distributed load $q(t)$ and a multiple number of responses (stresses, strains, or displacements at different positions) will be considered and (30) reduces to

$$R_i(t) = \int_0^t R_{Hi}(t-\tau) \frac{dq(\tau)}{d\tau} d\tau \quad (35)$$

where $R_{Hi}(t)$ ($i = 1, 2, \dots, m$) are functions of $D_j(t)$, $v_j(t)$, h_j , a , r , and z ($j = 1, 2, \dots, n$: layer number) and can be obtained through the following steps:

1. Pick a time, say, t_1 .
2. Get $D_j(t_1)$, $v_j(t_1)$ for $j = 1, 2, \dots, m$ from the material property curves.
3. Obtain the corresponding elastic solutions of the problem depicted in Fig. 1 with $E_j = 1/D_j(t_1)$, $v_j = v_j(t_1)$. These elastic solutions constitute $R_{Hi}(t_1)$ for $i = 1, 2, \dots, m$.
4. Repeat steps 1 to 3 for a number of different times, say, $t_1, t_2, t_3, \dots, t_N$ where typically $t_1 = 0$ and $t_N = t$ (the current time).
5. Obtain the functional expression $R_{Hi}(t)$ by fitting it to the established data set $\{R_{H1}(t_1), R_{H1}(t_2), \dots, R_{H1}(t_N)\}$.

The solutions in step 3 may be obtained either in closed-form or through a numerical procedure such as the finite element method. In the case of layered system, no closed form solution is available but the solutions either in integral representation as in (22) or from a finite element analysis can be used.

Once the unit response functions $R_{Hi}(t)$ are obtained, the viscoelastic responses $R_i(t)$ of the system to a general input history are obtained by (35). When the applied excitation is time-varying, the dynamic effects (inertia) need to be considered in computing the responses; however, if the time rate of input is reasonably small the inertia effects can be neglected. Only quasi-static situations will be considered in this study. The integration in (35) may be carried out either analytically or numerically. Analytical integration of (35) requires the functional representations of both $R_{Hi}(t)$ and $q(t)$ which should be simple enough to guarantee a closed form integration. For instance, each unit response function can be represented by a series of decaying exponentials as follows (the subscript i in $R_{Hi}(t)$ is dropped for brevity):

$$R_H(t) = \sum_{k=1}^K A_k \exp\left(-\frac{t}{\rho_k}\right) \quad (36)$$

where A_k and ρ_k ($k = 1, 2, \dots, K$) are constants. The time constants ρ_k are usually specified *a priori* such that they are separated by no more than one decade and A_k are then determined by fitting (36) to a discrete set of calculated values of R_H . Typically the number of terms K is determined so that at least one term for each decade of graphical data is present. The expression (36) is often referred to as *Prony* or *Dirichlet* series. The Prony series representation fits well to data of viscoelastic material properties or

mechanical responses that span over many decades of time. The series also has many advantages in terms of computational facility.

4. Time-Temperature Superposition And Effects Of Transient Temperatures

In general the mechanical properties of viscoelastic materials depend not only on loading time but also on temperature. Especially some of the mechanical properties of amorphous polymers have a strong dependence upon temperature. The linear thermoviscoelasticity theory does not allow, in general, the mechanical properties to vary with temperature, and the properties corresponding to a particular fixed temperature should be used throughout the solution procedure; otherwise the formulation becomes nonlinear in that the material property functions depend upon the temperature which again can only be determined when material property functions are known. However, there exists a special type of materials whose temperature dependence of mechanical properties is amenable to analytical description. This special class of materials is referred to as being *thermorheologically simple* and the corresponding description of temperature dependent properties was first proposed by Leaderman (1943) and was subsequently applied by other investigators (e.g., Schwarzl and Staverman 1952, Morland and Lee 1960). The simplifying feature of the thermorheologically simple materials is that when material property (e.g., relaxation modulus or creep compliance) curves measured at different constant temperatures are all plotted against time on a logarithmic scale, the curves can be superposed so as to form a single curve (which is called a *master curve*) corresponding to an arbitrary fixed temperature (*reference temperature*) by means of horizontal translation only. The horizontal distance between the master curve and any one of the isothermal

curves is independent of time. This feature has a very significant consequence in that the dependence of the material property upon both time and temperature can be represented by dependence upon a single variable called *reduced time*, and the feature is often referred to as *time-temperature superposition* or *reduced-time method*. In mathematical notation, e.g., for the uniaxial relaxation modulus,

$$E(t, T) = E_M(\xi) \quad (37)$$

where $E_M(\xi)$ is the master relaxation modulus corresponding to a reference temperature (T_R), and for constant temperatures,

$$\xi = \frac{t}{a_T} \quad (38)$$

where ξ and a_T are called *reduced time* (or *material time*) and *time-temperature shift factor*, respectively. The a_T is a temperature dependent material function which reflects the influence of temperature on internal viscosity of the material. One may obtain the relaxation modulus $E(t, T)$ if the master relaxation modulus $E_M(\xi)$ and the shift factor $a_T(T)$ are given; or, conversely, one may obtain $E_M(\xi)$ when $E(t, T)$ and $a_T(T)$ are given. For temperatures above the glass transition temperature of the material, the shift factor a_T for thermorheologically simple materials is usually expressed in the following form:

$$\log a_T = -\frac{c_1(T - T_R)}{c_2 + T - T_R} \quad (39)$$

where c_1 , c_2 , and T_R are constants. It is seen that the form of (39) is independent of the choice of T_R but the values of c_1 and c_2 depend on T_R . The constants c_1 and c_2 can be obtained by plotting $(T - T_R)$ against $(T - T_R)/\log a_T$; the slope and the intercept of the

resulting straight line are $-c_1$ and $-c_2$, respectively. The equation (39) is commonly referred to as *WLF equation* (Williams, Landel and Ferry 1955).

Now, the input-response relations of a thermorheologically simple linear viscoelastic medium can be expressed from (30) as follows:

$$R_i(t) = \int_0^t R_{Hi}(\xi - \xi') \frac{dI_j(\tau)}{d\tau} d\tau \quad (40)$$

which reduces, for the layered viscoelastic system under consideration with a single input $q(t)$, to

$$R_i(t) = \int_0^t R_{Hi}(\xi - \xi') \frac{dq(\tau)}{d\tau} d\tau \quad (41)$$

where

$$\xi' = \int_0^t \frac{1}{a_T} d\tau' \quad (42)$$

and $\xi = \xi'|_{\tau=t}$. The variable τ' in (42) is the dummy variable of integration and a_T is a function of temperature as represented in (39) and the temperature varies with time in general, i.e., $a_T = a_T(T(t))$. For constant temperatures (isothermal conditions), (42) reduces to

$$\xi' = \frac{\tau}{a_T} \quad (43)$$

and $\xi = \xi'|_{\tau=t} = t / a_T$ which was given by (38).

The significance of (40) is that the same unit response functions determined at a constant temperature can be used to calculate the responses at other constant or transient temperatures simply by replacing the physical time with the reduced time which accounts for the effects of both time and temperature. Moreover, when the temperatures are

constant, the Prony series representation of unit response function (36) in terms of reduced time becomes, upon substituting (38),

$$R_H(\xi) = \sum_{k=1}^K A_k \exp\left(-\frac{\xi}{\rho_k}\right) = \sum_{k=1}^K A_k \exp\left(-\frac{t}{\rho'_k}\right) \quad (44)$$

with the reduced time constant ρ'_k defined by

$$\rho'_k \equiv a_T \rho_k. \quad (45)$$

That is, the effects of different constant temperatures on the response of the system to the given input history can be accounted for simply through the changes of time constants of the Prony series ρ_k to ρ'_k according to (45). Analytical expression of the reduced time in terms of the physical time for transient temperatures is difficult to obtain directly from (39) and (42). However, it is usually possible to obtain the functional form of ξ' in terms of τ through an appropriate curve fitting. Then one can define an *effective* shift factor, $a_T^{\text{eff}} \equiv \tau/\xi'$, or

$$a_T^{\text{eff}}(\tau) \equiv \frac{\tau}{\int_0^\tau \frac{d\tau'}{a_T}}. \quad (46)$$

Now the same form of reduced time and reduced time constants as in (43) and (45) can be used for general transient temperature histories; i.e., (42) can be replaced by

$$\xi' = \frac{\tau}{a_T^{\text{eff}}(\tau)} \quad (47)$$

and likewise $\xi = \xi'|_{\tau=t} = t/a_T^{\text{eff}}(t)$, and (45) is generalized to

$$\rho'_k \equiv a_T^{\text{eff}}(t) \rho_k. \quad (48)$$

It should be emphasized that a_T^{eff} is not constant in general but a function of current time.

5. Illustrations: A Three-Layer Elastic/Viscoelastic Composite System

In order to illustrate the analysis procedure described so far, a three-layer system with a viscoelastic surface layer underlain by two elastic layers subjected to uniform circular load as depicted in Fig. 4 will be considered. This system closely simulates the structure of flexible pavement for roads and airfields. The viscoelastic surface layer corresponds to the asphalt concrete surface course and underlying two elastic layers to base course and subgrade, respectively. The thicknesses of top two layers are taken to be the same as the radius of the loaded area. The creep compliance of each layer normalized in D_3 is given in Fig. 5(a). The time-temperature shift factor a_T for the viscoelastic surface layer is given in Fig. 5(b). It is assumed that only the mechanical properties of the viscoelastic layer depend upon temperature and those of the elastic layers are not affected by temperature. Constant Poisson's ratios were used in the analysis for simplicity even though time-dependent Poisson's ratios may be accommodated without difficulties. Overall, the material properties taken are close to those of real pavement layers. The loading and temperature histories considered and their combination used in each of the illustration cases are given in Figures 6(a) - 6(c). The field variables and the positions at which these variables were evaluated are indicated in Fig. 7. The critical values of the variables usually take place along the layer interfaces. When the variable under consideration has a discontinuity across the layer boundary (interface), the values for the upper side of the boundary will be presented. For ease of computation and interpretation, the responses are presented in terms of normalized (dimensionless) field variables. The components of the stress and strain tensors and displacement vector are expressed as

multiples of q , qD_3 , and aqD_3 , respectively, where q is the intensity of the load, D_3 is the (constant) compliance of layer 3, and a is the radius of the loaded area.

First the response of the system under constant load and constant temperatures will be obtained, then the responses under transient load and constant temperatures, constant load and transient temperatures, and transient load and transient temperatures will be considered. A spatially homogeneous temperature distribution which does not induce heat conduction between the material particles is assumed. An existing computer code, ELSYM5 (Kopperman et al. 1986) for analysis of layered elastic systems, based on the integral representation similar to (22), was used to obtain the elastic solutions needed to generate the viscoelastic unit response functions. Even though the example taken is aimed at analysis of a typical flexible pavement structure, the solution procedure is applicable to other kinds of viscoelastic boundary value problems with various temperature conditions.

Case 1. Response to Constant Load and Constant Temperatures.

First we shall look into the response of the system under constant load and constant temperatures. A constant loading history $q_i(t)$ with an amplitude of q is applied at a constant (reference) temperature $T_i(t) = T_R = 25^\circ\text{C}$ (see Figs. 6(a) and (b)). As discussed above, the responses under this loading condition when divided by the amplitude q constitute the unit response functions $R_{Hi}(\xi)$ which will be used as kernels in obtaining the responses under general loading and temperature conditions according to (41). Since we are dealing with a linear system, the unit response functions of the system are obtained simply by dividing the responses to a constant load by the amplitude of the load. In Figs. 8 through 14, the unit responses of the variables chosen are presented. The abscissa is the

reduced time (or physical time in Figs. 13 and 14) on a logarithmic scale and the ordinates for different variables are either on linear or logarithmic scales depending on the range of the data presented. Reduced time is the time rescaled by temperature factor a_T according to, for constant temperatures, (38). At the reference temperature the shift factor becomes unity and the reduced time equals the physical time (i.e., for $T = T_R$, $a_T = 1$ and $\xi = t$).

The vertical displacements evaluated at three different positions (#1, #2, and #3 in Fig. 7) are plotted in Fig. 8 on a log-log scale. It is seen that the overall pattern of time dependence of the displacement at position #1 closely follows that of $D_1(t)$ in Fig. 5(a) although the degree of dependence is weaker compared to $D_1(t)$. The displacement contribution from the top viscoelastic layer is negligibly small at short loading times but it gradually dominates the total surface displacement with passage of time. The middle layer contributes relatively small portions toward the total surface displacement. The surface displacement at short loading times is mostly due to compression of the bottom layer with an infinite depth. It is to be noted that not only the surface displacement is time-varying but displacements at the two interfaces (positions #2 and #3) below which are elastic layers are also time-dependent, which is the result of time-dependent stress redistribution taking place within the system. The zero-time value (which is not shown because of the logarithmic scale) of the surface displacement is $w = 0.281 qaD_3$ (or qa/E_3) which compares well with that given by Thenn de Barros (1966) for a three-layer elastic system; he gave $w = 0.214 qa/E_3$ for $E_1/E_2 = 50$, $E_2/E_3 = 5$, $v_1 = v_2 = v_3 = .35$, and $h_1/a = h_2/a = 1.25$. The parameters for our case are $E_1/E_2 = D_2/D_1(t=0) = 40$, $E_2/E_3 = D_3/D_2 = 5$, $v_1 = 0.35$, $v_2 = v_3 = .45$, and $h_1/a = h_2/a = 1.0$. When the parameters for both cases were equated through proper interpolations, the resulting displacements matched very closely.

The stresses at positions #1, #2, and #3 are presented in Figs. 9 and 10. Tensile stresses are positive. In an axisymmetric state of stress, only four nonzero stress components, σ_{rr} , $\sigma_{\theta\theta}$, σ_{zz} , and τ_{rz} , exist. Along the axis of symmetry ($r = 0$), $\tau_{rz} = 0$ and $\sigma_{rr} = \sigma_{\theta\theta}$. The major and minor principal stresses along the axis of symmetry ($r = 0$) coincide with either σ_{zz} or σ_{rr} ($= \sigma_{\theta\theta}$) depending on the vertical position z . The vertical stress σ_{zz} at position #1 (beneath the loading center) remains a constant value of $-q$ as prescribed by the traction boundary condition (Fig. 9). The σ_{zz} 's at positions #2 (the interface between layer 1 and layer 2) and at position #3 (the interface between layer 2 and layer 3) are initially close to zero but pick up gradually with loading time until they reach asymptotic values. The horizontal stress σ_{rr} ($= \sigma_{\theta\theta}$) at #1 is compressive and relaxes with time while the σ_{rr} ($= \sigma_{\theta\theta}$) at #2 is initially tensile and relaxes with time and becomes compressive at a certain loading time (Fig. 10). On the other hand, σ_{rr} ($= \sigma_{\theta\theta}$) at #3 remains tensile throughout the loading time and increases gradually towards an asymptotic value. From Fig. 10, it can be seen that at short loading times the lateral stresses (σ_{rr} and $\sigma_{\theta\theta}$) within the top layer varies from maximum compressive at the top surface to maximum tensile at the bottom; this situation simulates a plate (or a mat) on an elastic foundation with loading on its top surface. It is to be noted that across the layer interfaces the tractions are in equilibrium and therefore σ_{zz} 's are continuous as indicated by (11), but σ_{rr} 's and $\sigma_{\theta\theta}$'s are not necessarily continuous across the interfaces.

Variations of strains with time at selected positions (#1, #2, and #3) are shown in Figs. 11 and 12. Like stresses, in an axisymmetric state of stress, only four nonzero strain components, ϵ_{rr} , $\epsilon_{\theta\theta}$, ϵ_{zz} , and γ_{rz} , are present. Further, along the axis of symmetry ($r = 0$),

$\gamma_{zz} = 0$ and $\epsilon_{rr} = \epsilon_{\theta\theta}$, and the major and minor principal strains coincide with either ϵ_{zz} or ϵ_{rr} ($=\epsilon_{\theta\theta}$). Across an interface between different layers, ϵ_{rr} , $\epsilon_{\theta\theta}$ are continuous as the lateral displacements u and v are continuous along the interfaces but ϵ_{zz} 's (the gradient of w with respect to z) are not necessarily continuous. The vertical strains ϵ_{zz} 's at positions #1 and #2 increase rapidly with time (Fig. 11) and when plotted on a log-log scale the pattern of time-dependence of these variables looks much similar to that of the creep compliance $D_1(t)$. The ϵ_{zz} at position #3 also increases with time but the time-dependence is very weak compared to those at #1 and #2. The ϵ_{zz} 's are all compressive throughout the loading time. The lateral strains ϵ_{rr} ($=\epsilon_{\theta\theta}$)'s at #1 and #2 are compressive and tensile, respectively, and pick up until certain loading time after which they approach gradually towards zeros (Fig. 12). The ϵ_{rr} ($=\epsilon_{\theta\theta}$) at #3 is tensile and increases until it reaches an asymptotic value.

It is interesting to note that not only displacements and strains are time-dependent but stresses also vary with time. For an isotropic homogeneous viscoelastic body with constant Poisson's ratio subjected to constant boundary tractions, only displacements (and strains) are supposed to be time-dependent with stresses being time-independent. For example, in an isotropic homogeneous viscoelastic halfspace subjected to constant surface load (Boussinesq problem), the stresses are time-invariant. However, in the case of layered viscoelastic system, interface boundary conditions (in which both displacements and tractions are specified) cause the stresses to vary with time.

So far the responses with reduced time have been presented and discussed. However, a single master curve defined at a particular temperature (at the reference temperature of 25°C in our case) can be split into a number of isothermal curves as long as the shift factor a_T at each temperature level is given. Isothermal curves for two selected

variables (w at #1 and σ_{zz} at #2) are presented in Figs. 13 and 14. They are generated from their corresponding master curves introduced in Figs. 8 and 9, respectively, and using the shift factor taken from Fig. 5(b) for each temperature level considered. The reduced time can be split into physical time and temperature (through a_T) according to (38). Isothermal curves for other variables may be generated similarly.

Case 2. Response to Transient Load and Constant Temperatures.

The responses of the system subjected to general transient loading and constant temperatures can be determined by the linear superposition integral of the unit response functions and the loading rate according to (35). A haversine loading history $q_2(t)$ with an amplitude of q as shown in Fig. 6(a) was considered. This particular loading configuration closely simulates the loading effect on the pavement surface from a moving wheel (for a vehicle speed of 30 mph; Barksdale 1971). Constant temperatures $T_1(t)$ at four different levels as shown in Fig. 6(b) were considered. The integral in (35) was carried out analytically (see Appendix I) with the Prony series-represented R_H and the haversine loading history.

The vertical displacement w at position #1 and the vertical stress σ_{zz} at position #2 at each temperature level considered are given in Figs. 15 and 16, respectively. The effects of temperature are significant especially at high temperatures. It is observed that, due to viscoelasticity, the times at which the peak deflections or the peak stresses occur do not coincide with, but lags behind, the peak loading time ($t = .015$ sec). Also at the end of loading ($t = .03$ sec), the displacements and the stresses do not return to zero, which is consistent with common observations in a nondestructive field pavement evaluation test (e.g., the Falling Weight Deflectometer test). The σ_{zz} for $T = 50^\circ\text{C}$ drops rather rapidly

near the end of loading because at high temperatures the unit response σ_{zz} (see Fig. 14) levels off at early loading times.

Case 3. Response to Constant Load and Transient Temperatures.

The responses under constant load and transient temperatures can be obtained by simply replacing the physical time with the reduced time as the argument of the unit response functions which have been obtained in Case 1; physical time t in (26) is replaced by reduced time ξ defined by (47). The constant loading history $q_1(t)$ in Fig. 6(a) and two different types of haversine temperature histories $T_2(t)$ and $T_3(t)$ as shown in Fig. 6(b) were considered. The temperature histories are fictitious and have been chosen simply for illustration of the proposed analysis procedure. As in Case 2, the vertical displacement at #1 and vertical stress at #2 were evaluated for the two haversine temperature histories and also for the two constant temperature histories (0°C and 50°C). The results are presented in Figs. 17 and 18. The responses to constant temperatures (0°C and 50°C) given earlier in Figs. 13 and 14 are re-presented here. The responses depend significantly on temperature histories. It is interesting to note that under the temperature history $T_3(t)$, the time-dependence of responses happens to be almost perfectly offset by temperature effects for most of the loading duration. The shift factor (a_T) and the effective shift factor (a_T^{eff}) defined by (46) for temperature histories $T_2(t)$ and $T_3(t)$ are given in Fig. 19.

Case 4. Response to Transient Load and Transient Temperatures.

The responses of the system under most general combination of load and temperature conditions, i.e., transient load and transient temperatures, can now be obtained according to (41). Again, the unit response functions R_{Hi} obtained in Case 1 will be used. Since both load and temperature are transient, the integral in (41) can best be

performed numerically. In Appendix II, a numerical procedure for computing responses under transient loading and transient temperatures is given. A Prony series representation of R_H , effective shift factor, and the trapezoidal-rule quadrature were incorporated.

The haversine loading $q_2(t)$ and temperature histories $T_2(t)$ and $T_3(t)$ as shown in Figs. 6(a) and (b) were considered. The same variables, w at #1 and σ_{zz} at #2, as were considered before are evaluated and presented in Figs. 20 and 21. Again the responses are quite different for different temperature histories. It can be seen that the temperatures corresponding to high load levels have dominant influence on the responses. The tail part (near $t = .03$ sec) of responses under $T_2(t)$ temperature history does not drop as much as others, which can be explained by the fact that most relaxation took place during when load and temperature were highest and then both load and temperature dropped but could not sufficiently offset the relaxation that already took place. The responses to constant temperatures (0°C and 50°C) given earlier in Figs. 15 and 16 are included for comparison.

6. Concluding Remarks

A procedure for the analysis of stresses and displacements in a viscoelastic layered system subjected to transient loading and transient and spatially homogeneous temperature conditions was developed and illustrated. The viscoelastic solutions were obtained through a linear convolution integral of the unit response functions and the time rate of loading. The existing elastic solutions were used to determine the unit response functions for the corresponding viscoelastic problem based on the correspondence existing between the elastic and viscoelastic unit responses. The solution procedure is based on linear superposition of the responses to incremental constant loads applied at different times and

does not require the steps associated with the usual Laplace transform-based elastic-viscoelastic correspondence principle; i.e., no integral transforms and their inversions are needed. Each unit response function was represented by a series of decaying exponentials (Prony series), and the convolution integrals were carried out taking advantage of the numerical facilities associated with this series representation.

The effects of temperature on the mechanical responses of the system were accounted for through the use of the *reduced* time. It was assumed that the system is made up of thermorheologically simple materials and the usual time-temperature superposition principle holds, which has been proven valid for many amorphous polymers and polymeric composites including asphalt concrete (Pagen 1965, Kim and Lee 1995). For an isothermal condition the constant shift factor was used, and the for a general transient temperature history the *effective* shift factor (which is a function of time) was utilized. With the use of effective shift factor and the Prony series representation of unit response functions, one may carry out the convolution integral analytically for a large class of problems.

Only a spatially uniform temperature distribution has been considered. A nonuniform temperature distribution induces heat conduction within the system and a thermal-mechanical coupling needs to be accounted for. Also thermal expansion has not been considered in our formulation for simplicity; however, no particular difficulties are expected when extra thermal expansion terms are included in the constitutive equations.

Several other assumptions were made in the development of the procedure. The investigation has been restricted to a quasi-static analysis and no inertia effects were taken into account. The materials involved are assumed to be linear, homogeneous, and

isotropic. The system was assumed to be semi-infinite; normally the real structure has finite geometrical boundaries. Even though the illustrations were concerned with the three-layer elastic/viscoelastic composite system, the procedure introduced is applicable to a wide range of viscoelastic systems (or elastic/viscoelastic composite systems) subjected to transient loading and/or transient temperature histories as long as the materials that constitute the system are linear viscoelastic and thermorheologically simple.

Appendix I. Computation of Responses to Transient (Haversine) Load and Constant Temperatures:

Let us consider the response of the system subjected to a haversine loading history $q_2(t)$ (Fig. 6(a)) at the reference temperature ($T = 25^\circ\text{C}$, $a_T = 1$, $\xi = t$). Substituting the Prony series representation for R_H (36) and the haversine loading function

$$q(t) = \sin \omega t \quad \text{for } 0 \leq t \leq .03 \quad (\text{A1})$$

into (35) with $i = 1$, one obtains

$$\begin{aligned} R(t) &= \int_0^t R_H(t-\tau) \frac{dq(\tau)}{d\tau} d\tau = \int_0^t \sum_{k=1}^K R_k \exp\left(-\frac{t-\tau}{\rho_k}\right) \omega \cos \omega \tau d\tau \\ &= \omega \sum_{k=1}^K R_k \exp\left(-\frac{t}{\rho_k}\right) \int_0^t \exp\left(\frac{\tau}{\rho_k}\right) \cos \omega \tau d\tau \end{aligned} \quad (\text{A2})$$

where $\omega = 2\pi/.06$. However, the integral in the last equation of (A2) can be analytically carried out using the following formula (e.g., CRC 1984, p279):

$$\int e^{a\tau} \cos(b\tau) d\tau = \frac{e^{a\tau}}{a^2 + b^2} (a \cos b\tau + b \sin b\tau) \quad (\text{A3})$$

Applying (A3) to the last integral in (A2) and rearranging

$$R(t) = \sum_{k=1}^K \frac{R_k \omega \rho_k}{1 + \omega^2 \rho_k^2} \left(\cos \omega t + \omega \rho_k \sin \omega t - \exp\left(-\frac{t}{\rho_k}\right) \right) \quad \text{for } 0 \leq t \leq .03 \quad (\text{A4})$$

For constant temperatures other than the reference temperature, (A4), with ρ_k replaced by $\rho'_k = a_T \rho_k$ according to (45), will give the required responses.

Appendix II. Computation of Responses to General Transient Load and Transient Temperatures:

Let us again assume that the unit response function R_H is made available and is represented by the Prony series (36) and the effective shift factor a_T^{eff} is computed according to (46) for the given transient temperature history. Then for an arbitrary transient load $q(t)$, (41) becomes, with $i = 1$,

$$\begin{aligned} R(t) &= \int_0^t R_H(\xi - \xi') \frac{dq(\tau)}{d\tau} d\tau = \int_0^t \sum_{k=1}^K R_k \exp\left(-\frac{\xi - \xi'}{\rho_k}\right) \frac{dq(\tau)}{d\tau} d\tau \\ &= \int_0^t \sum_{k=1}^K R_k \exp\left(-\frac{t}{\rho'_k(t)} + \frac{\tau}{\rho'_k(\tau)}\right) \frac{dq(\tau)}{d\tau} d\tau = \sum_{i=1}^N \int_{\tau_i}^{\tau_{i+1}} \sum_{k=1}^K R_k \exp\left(-\frac{t}{\rho'_k(t)} + \frac{\tau}{\rho'_k(\tau)}\right) \frac{dq(\tau)}{d\tau} d\tau \end{aligned} \quad (\text{A5})$$

Applying the simple trapezoidal rule to the last integral of (A5) with a range $\tau_i \leq \tau \leq \tau_{i+1}$,

$$R(t) = \frac{1}{2} \sum_{i=1}^N \sum_{k=1}^K R_k \left[\exp\left(-\frac{t}{\rho'_k(t)} + \frac{\tau_i}{\rho'_k(\tau_i)}\right) + \exp\left(-\frac{t}{\rho'_k(t)} + \frac{\tau_{i+1}}{\rho'_k(\tau_{i+1})}\right) \right] [q(\tau_{i+1}) - q(\tau_i)] \quad (\text{A6})$$

where $\tau_1 = 0$, $\tau_{N+1} = t$ (current time), $\rho'_k(t) = a_T^{\text{eff}}(t) \rho_k$, and $\rho'_k(\tau_i) = a_T^{\text{eff}}(\tau_i) \rho_k$.

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Notations

The following symbols are used in this study:

a = radius of loaded area

A_k = Prony series coefficients

a_T = time-temperature shift factor

a_T^{eff} = effective time-temperature shift factor

$D(t)$ = uniaxial creep compliance

$E(t)$ = uniaxial relaxation modulus

h_i = thickness of layer i

$H(t)$ = Heaviside unit step function

$I(t)$ = input

$J_0(\cdot)$ = Bessel function of the first kind and order zero

$J_1(\cdot)$ = Bessel function of the first kind and order one

q = load

$R(t)$ = response

$R_H(t)$ = unit response

t = time

T = temperature

T_R = reference temperature

u, w = r- and z-components of a displacement vector

$\varepsilon_{rr}, \varepsilon_{\theta\theta}, \varepsilon_{zz}, \gamma_{rz}$ = normal and shear components of a strain tensor

ϕ = Love's stress function

ν = Poisson's ratio

ρ_k = time constants in a Prony series

ρ'_k = reduced time constants in a Prony series

$\sigma_{rr}, \sigma_{\theta\theta}, \sigma_{zz}, \tau_{rz}$ = normal and shear components of a stress tensor

ξ = reduced time

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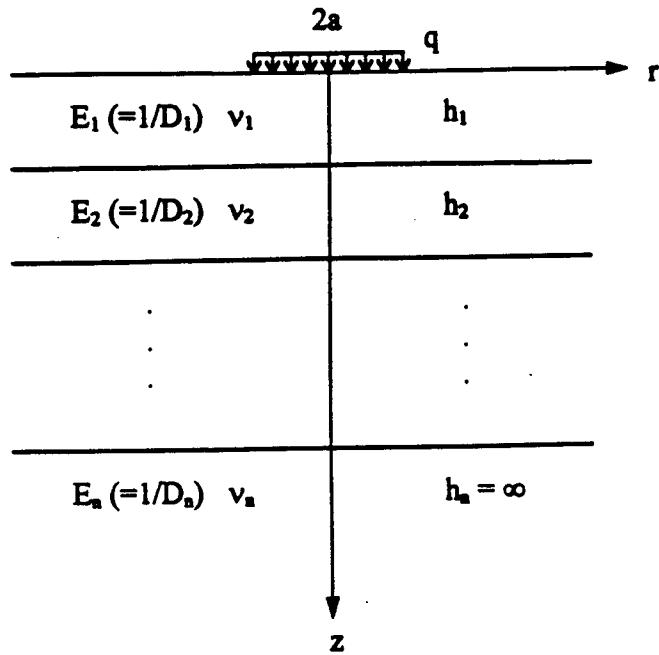
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Nonzero Field Variables:

u, w
 $\sigma_{rr} \sigma_{\theta\theta} \sigma_{zz} \tau_{rz}$
 $\epsilon_{rr} \epsilon_{\theta\theta} \epsilon_{zz} \gamma_{rz}$

Fig. 1. An n -layer elastic half-space subjected to a uniform circular load.

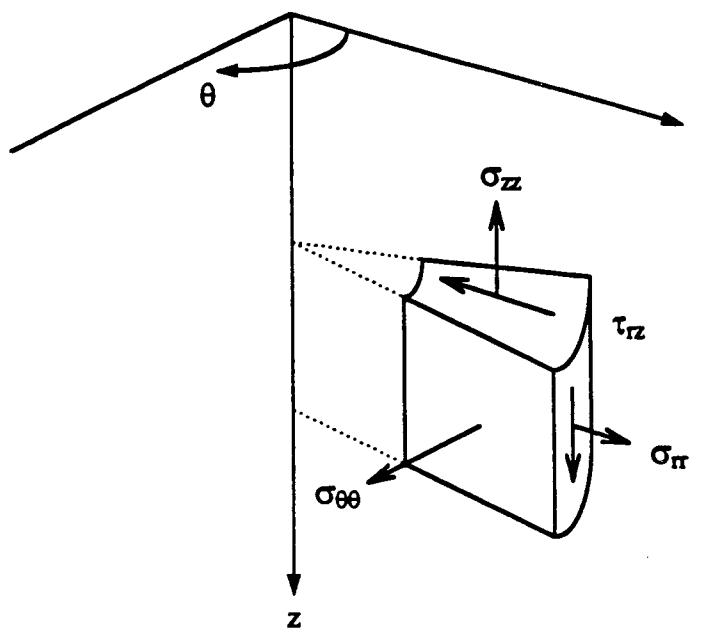


Fig. 2. The nonzero components of stress tensor in bodies of revolution under axisymmetric loading.

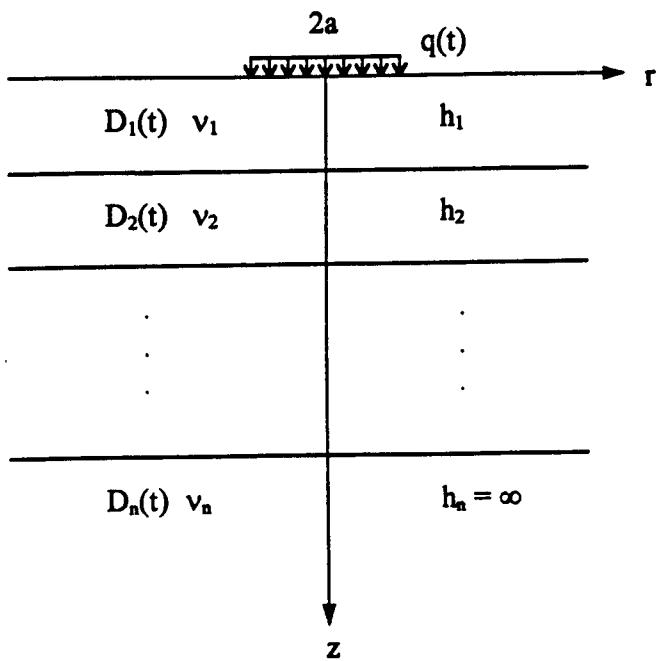


Fig. 3. An n -layer viscoelastic half-space subjected to a uniform circular load.

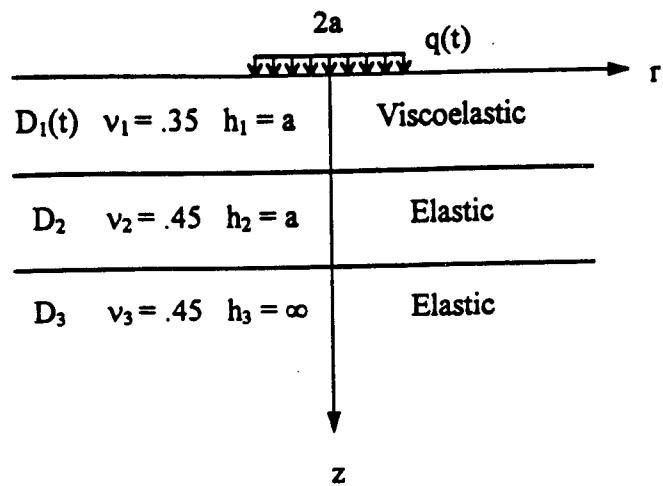


Fig. 4. A three-layer elastic/viscoelastic composite system subjected to a uniform circular load.

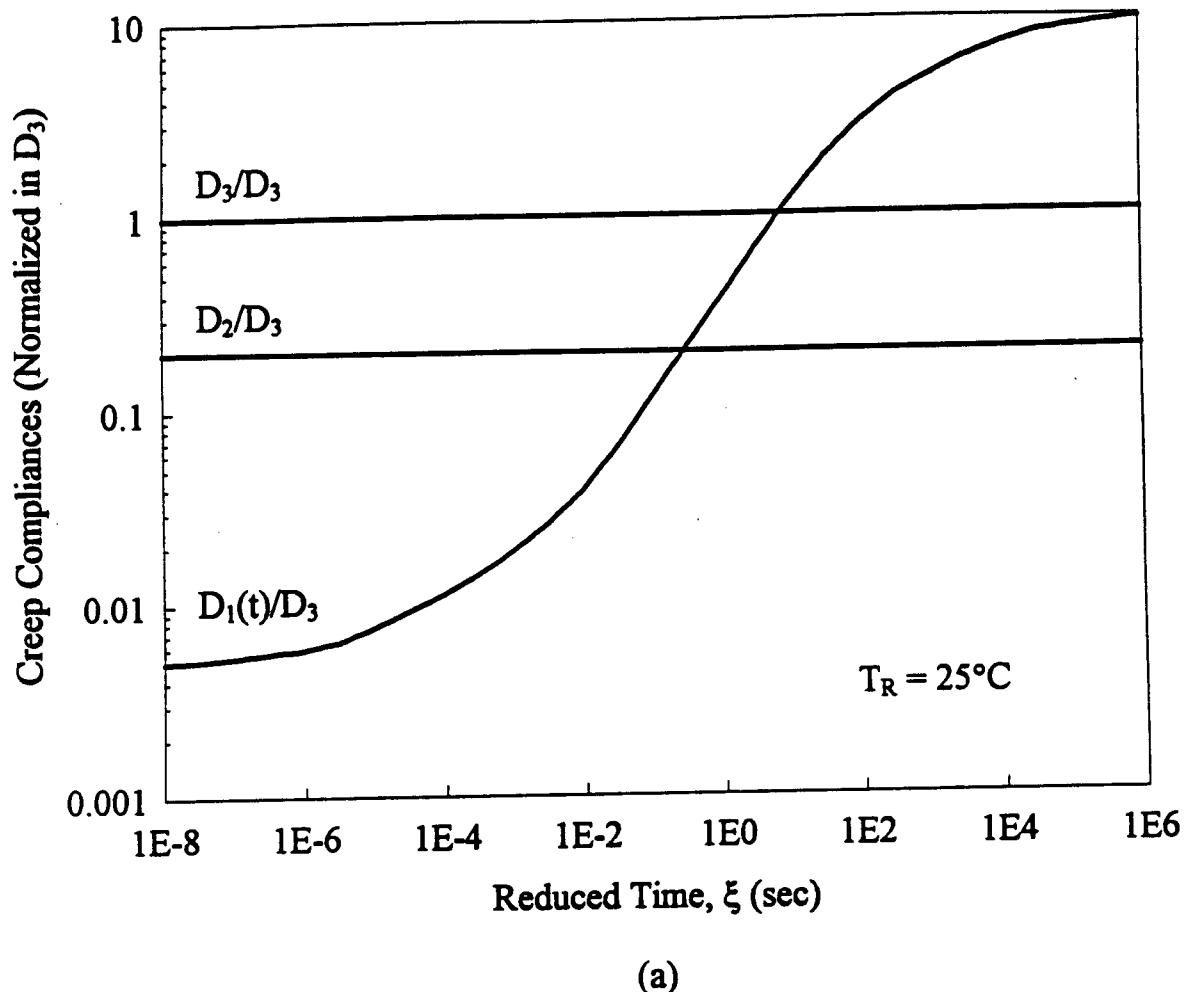


Fig. 5. Material properties. (a) Creep compliances of each layer. (b) Time-temperature shift factor of layer 1.

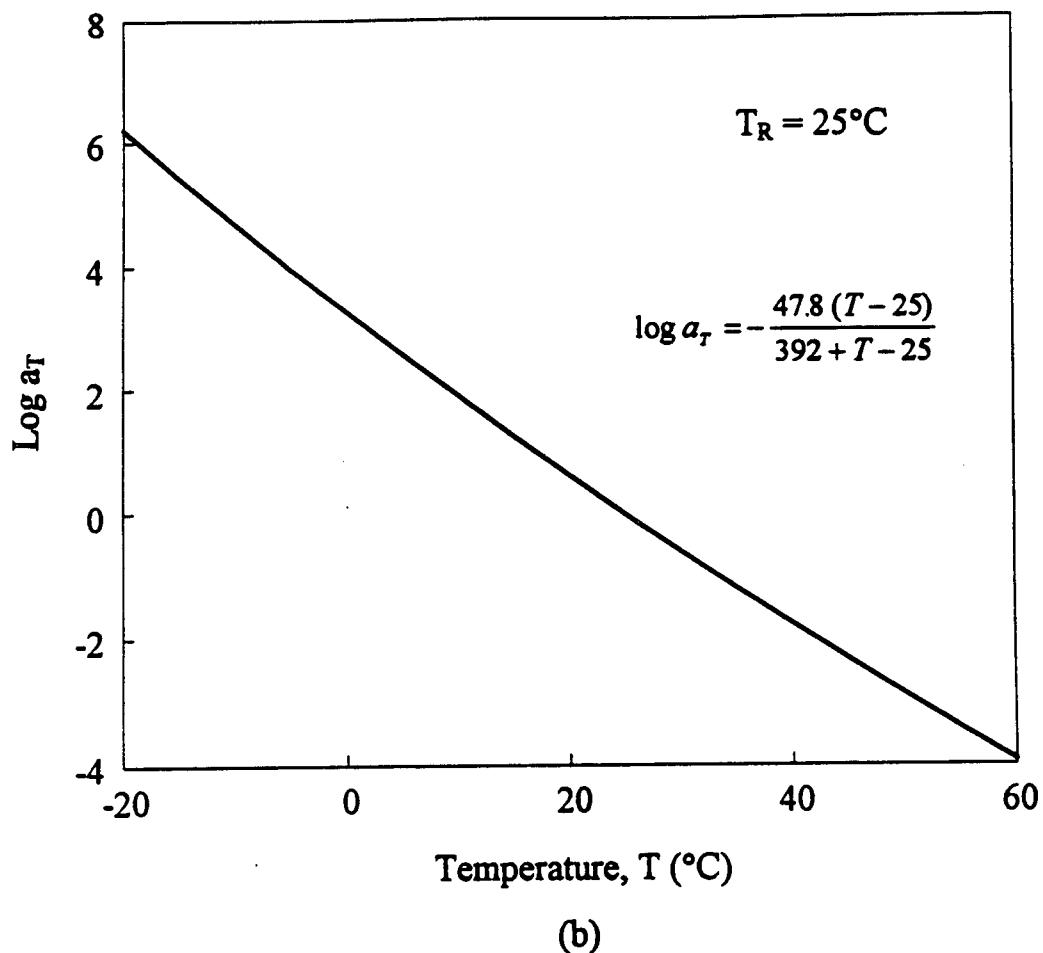
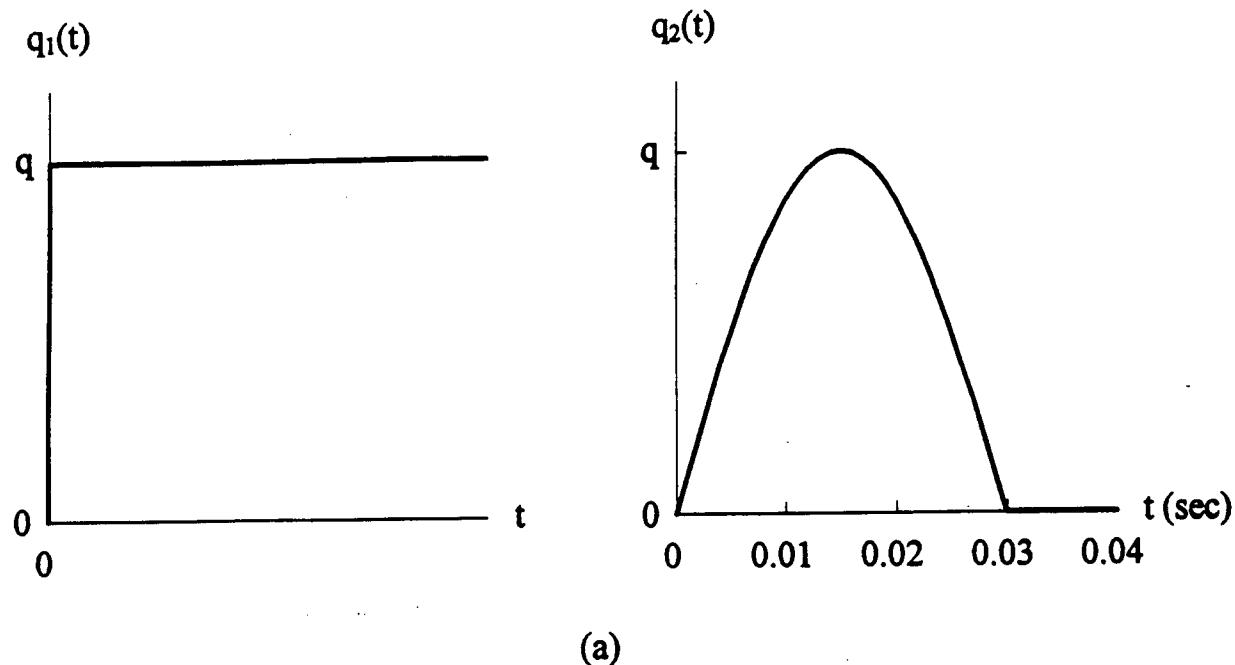


Fig. 5. (cont.) Material properties. (a) Creep compliances of each layer. (b) Time-temperature shift factor of layer 1.



(a)

Fig. 6. Loading and temperature histories considered in illustrations.
(a) Loading histories. (b) Temperature histories. (c) Loading and temperature combination for each case of illustration.

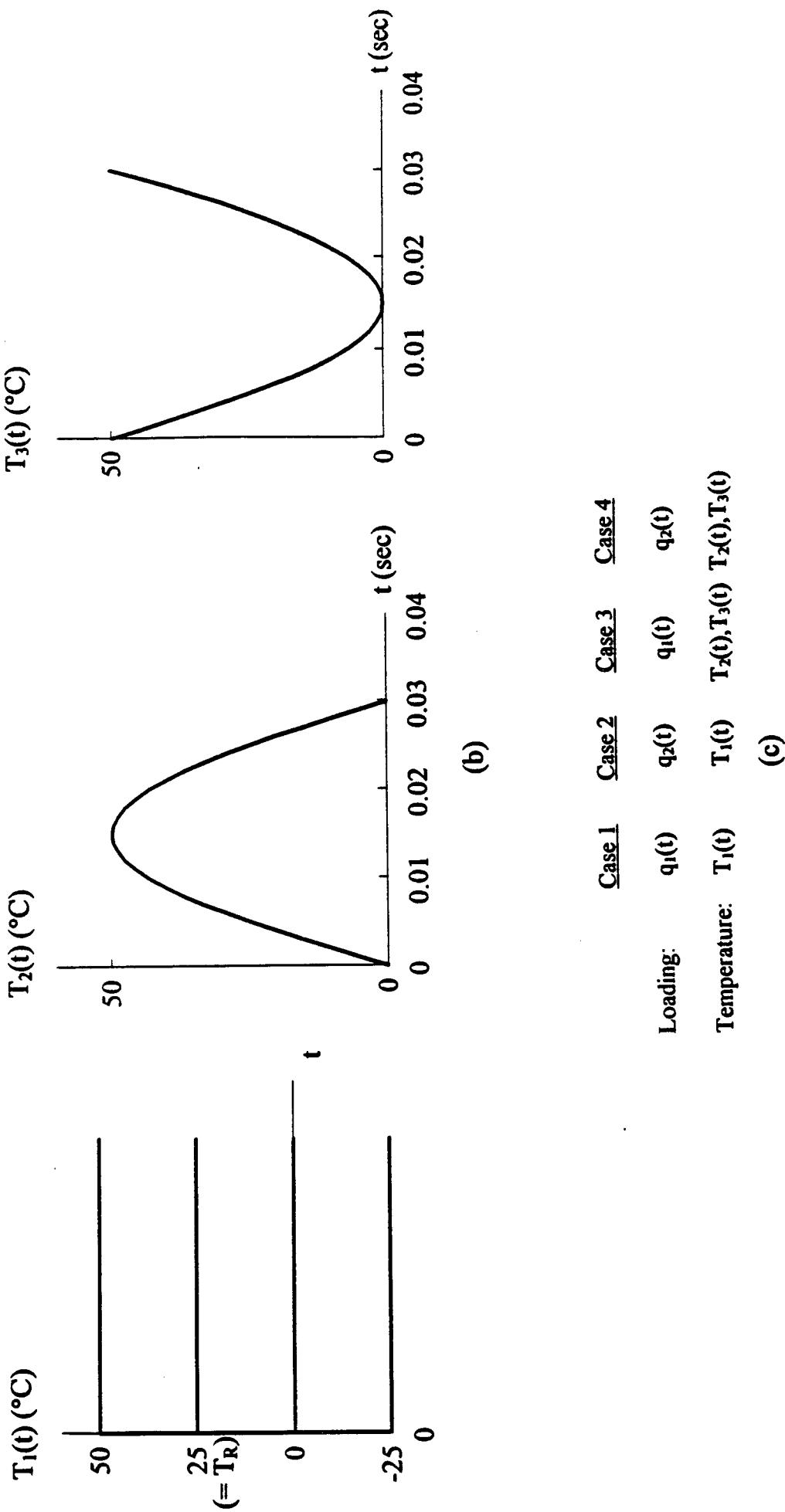
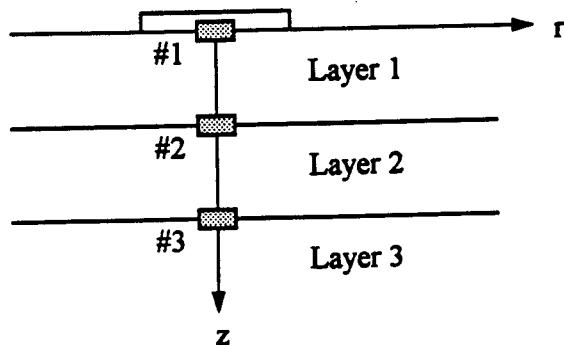


Fig. 6. (cont.) Loading and temperature histories considered in illustrations.
 (a) Loading histories. (b) Temperature histories. (c) Loading and temperature combination for each case of illustration.



<u>Evaluation Positions</u>	<u>Coordinates</u>	<u>Materials</u>
#1	$r=0 z=0$	Layer 1
#2	$r=0 z=a$	Layer 1
#3	$r=0 z=2a$	Layer 2

Fig. 7. Positions at which field variables are evaluated.

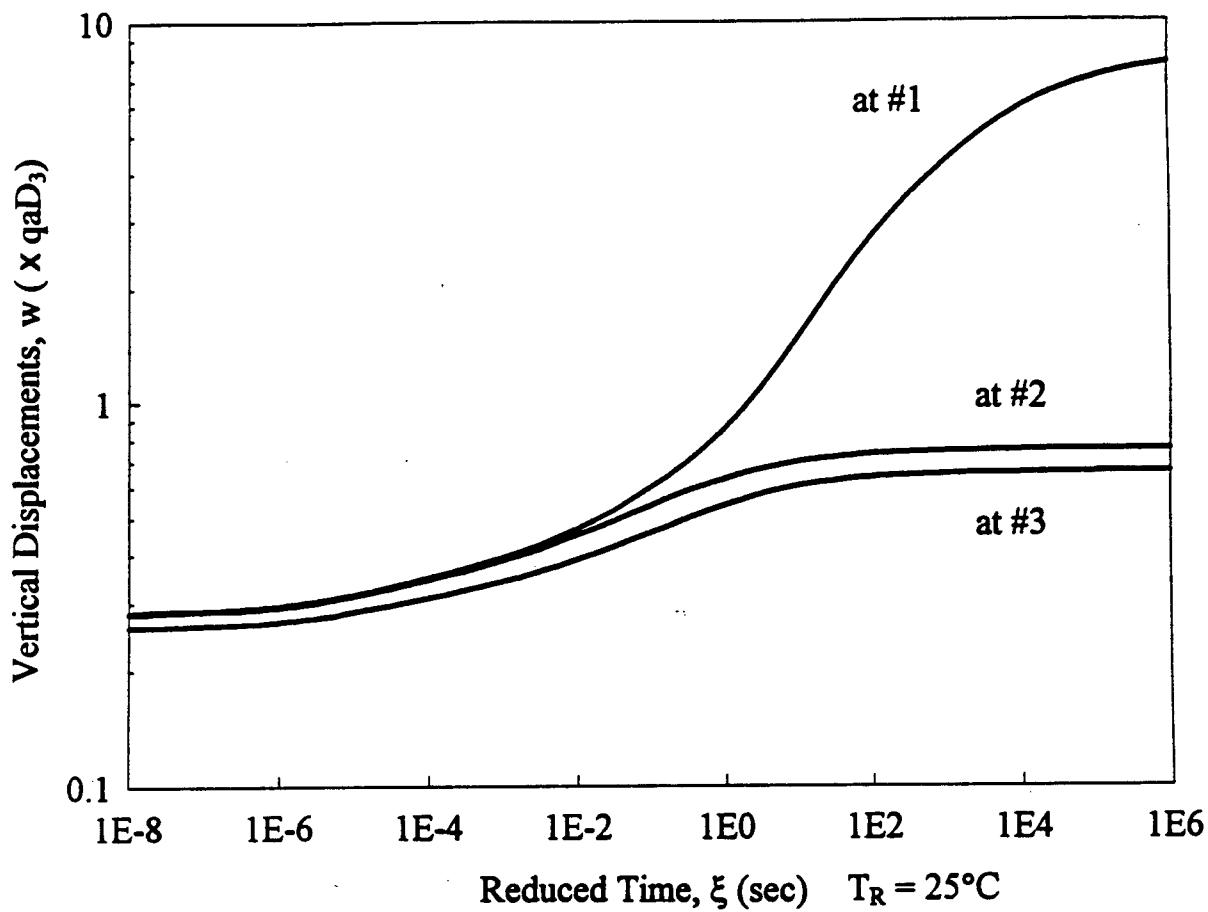


Fig. 8. Vertical displacements under constant load and constant (reference) temperature (Case 1).

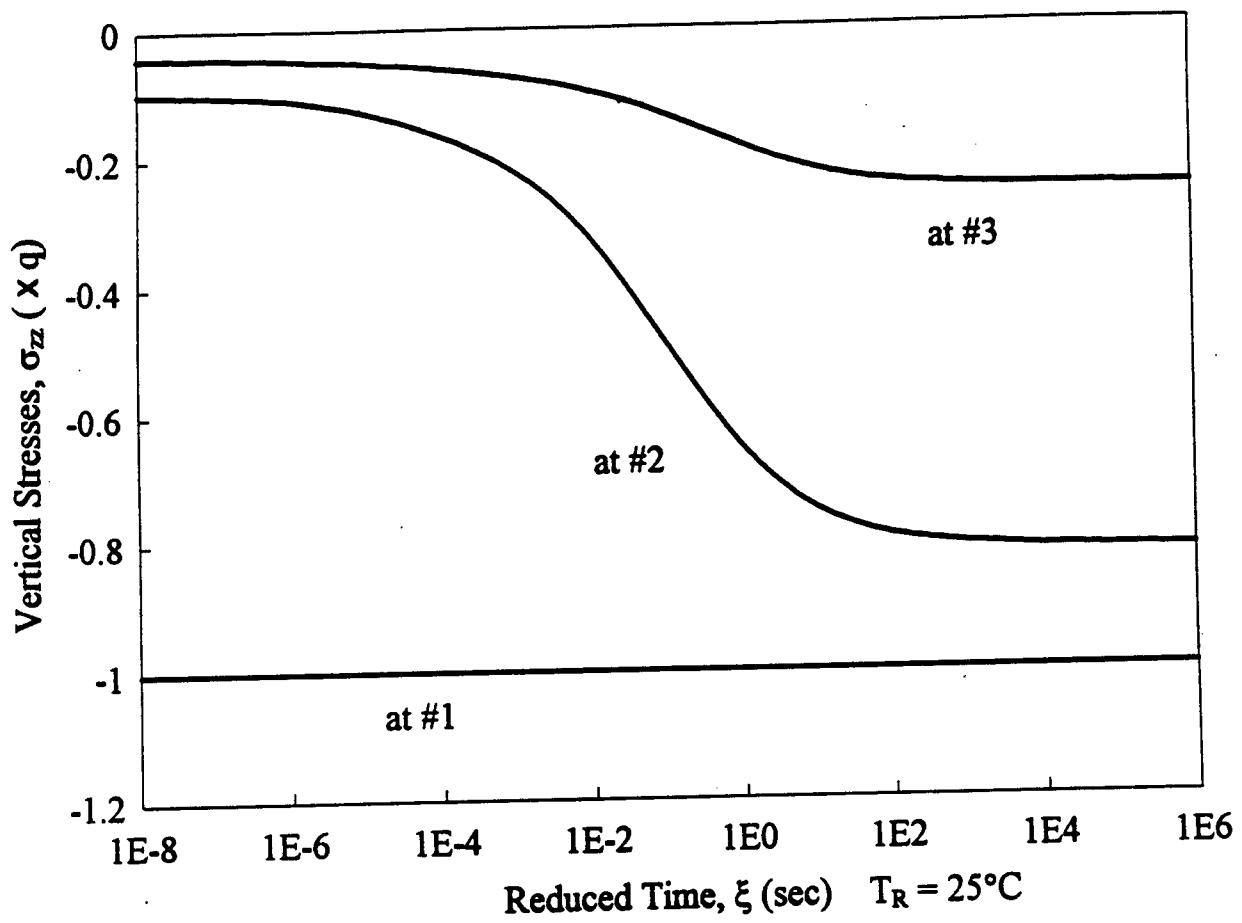


Fig. 9. Vertical stresses under constant load and constant (reference) temperature (Case 1).

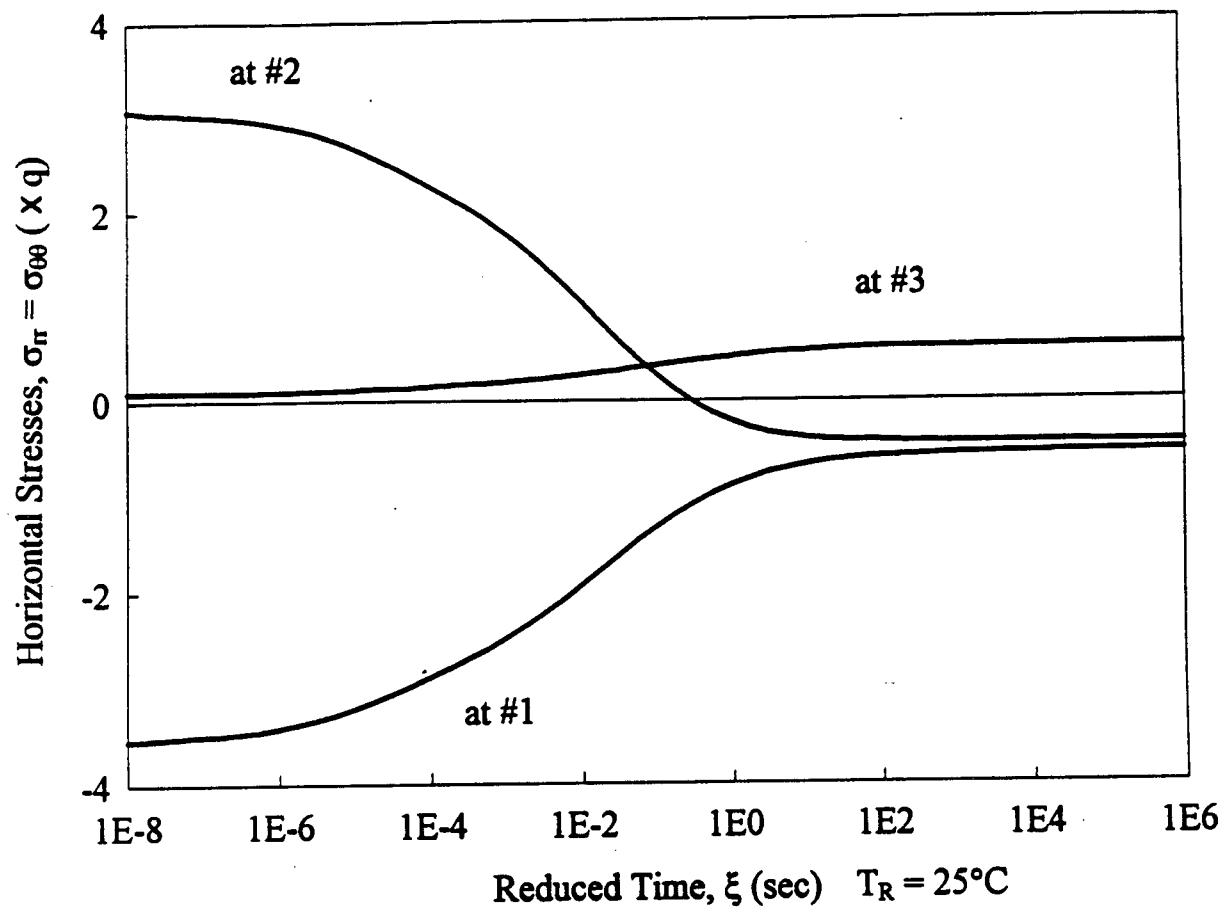


Fig. 10. Horizontal stresses under constant load and constant (reference) temperature (Case 1).

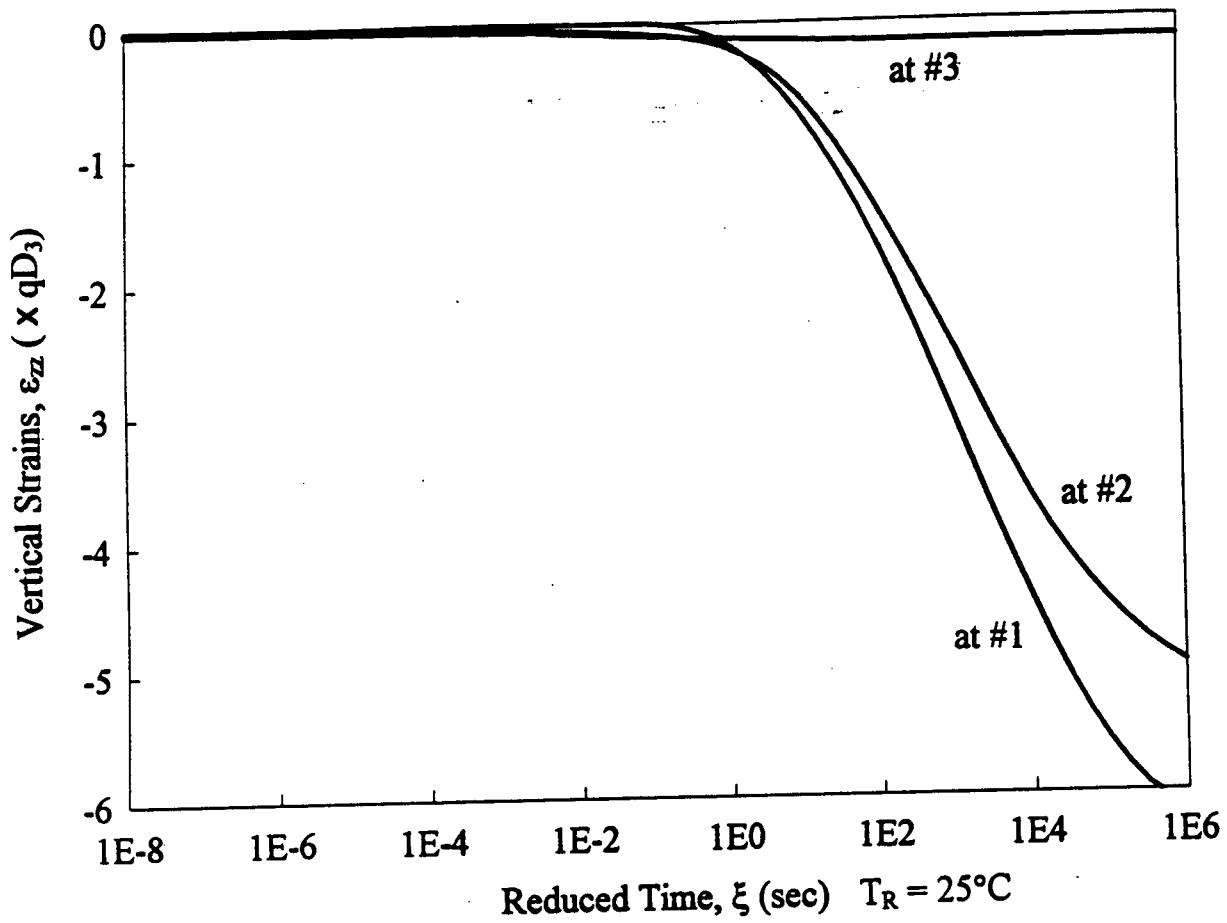


Fig. 11. Vertical strains under constant load and constant (reference) temperature (Case 1).

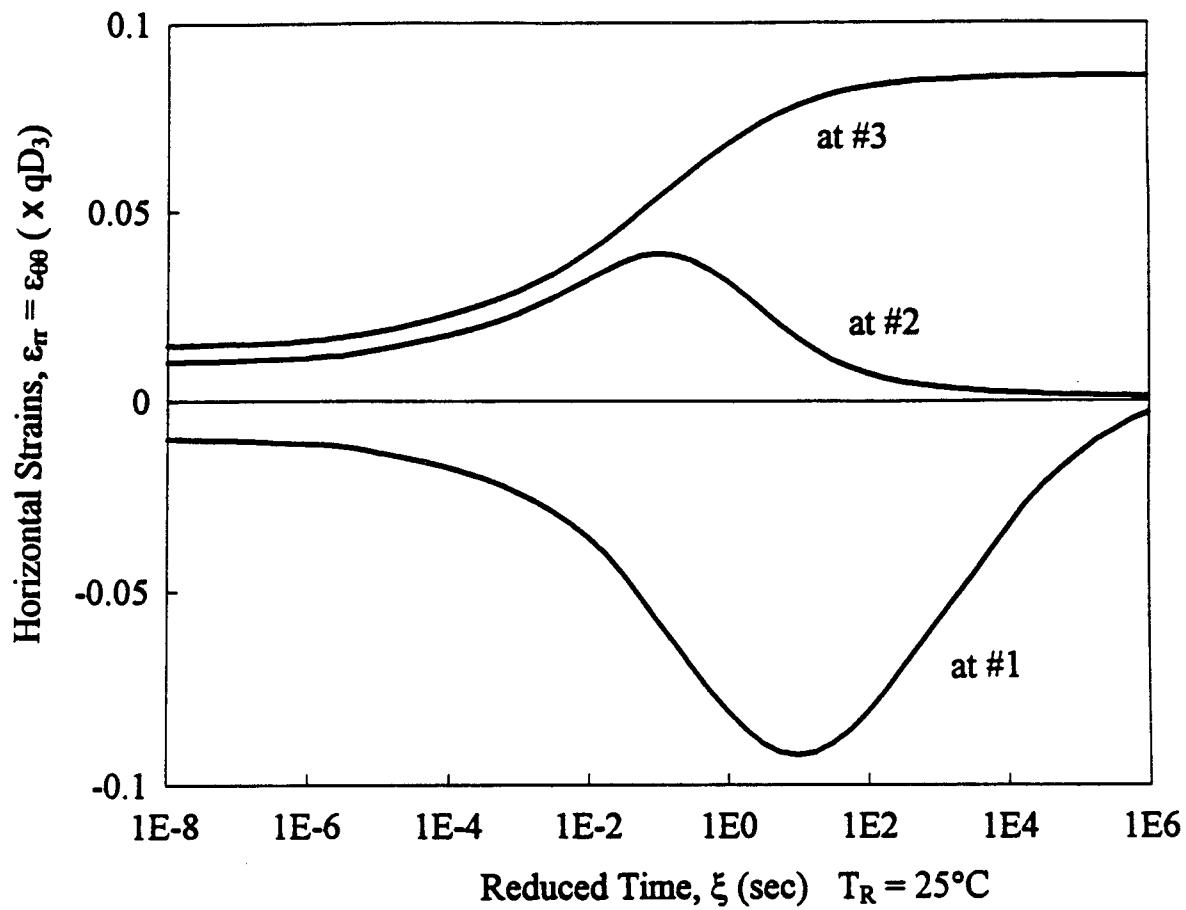


Fig. 12. Horizontal strains under constant load and constant (reference) temperature (Case 1).

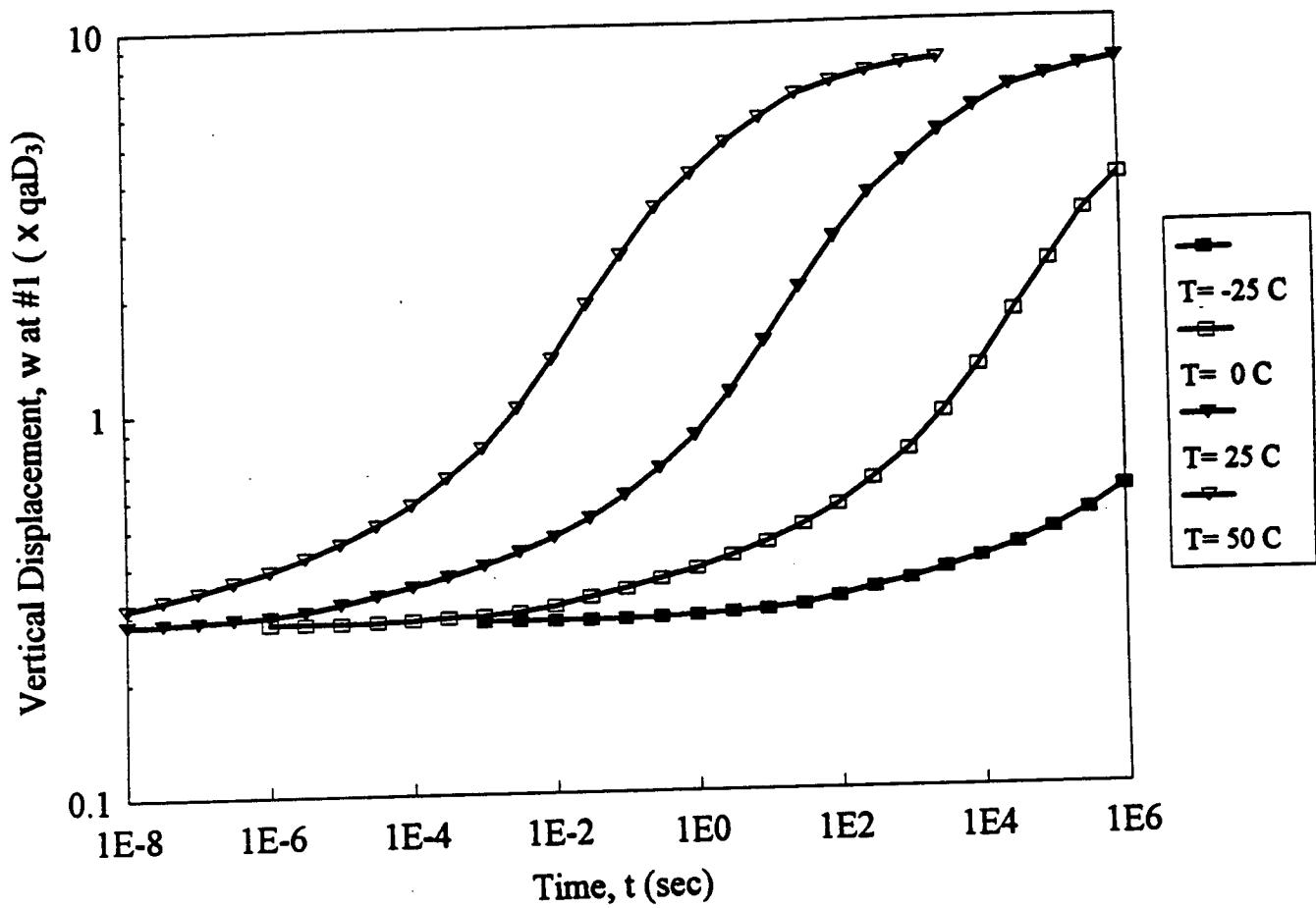


Fig. 13. Vertical displacement at position #1 under constant load and constant temperatures (Case 1).

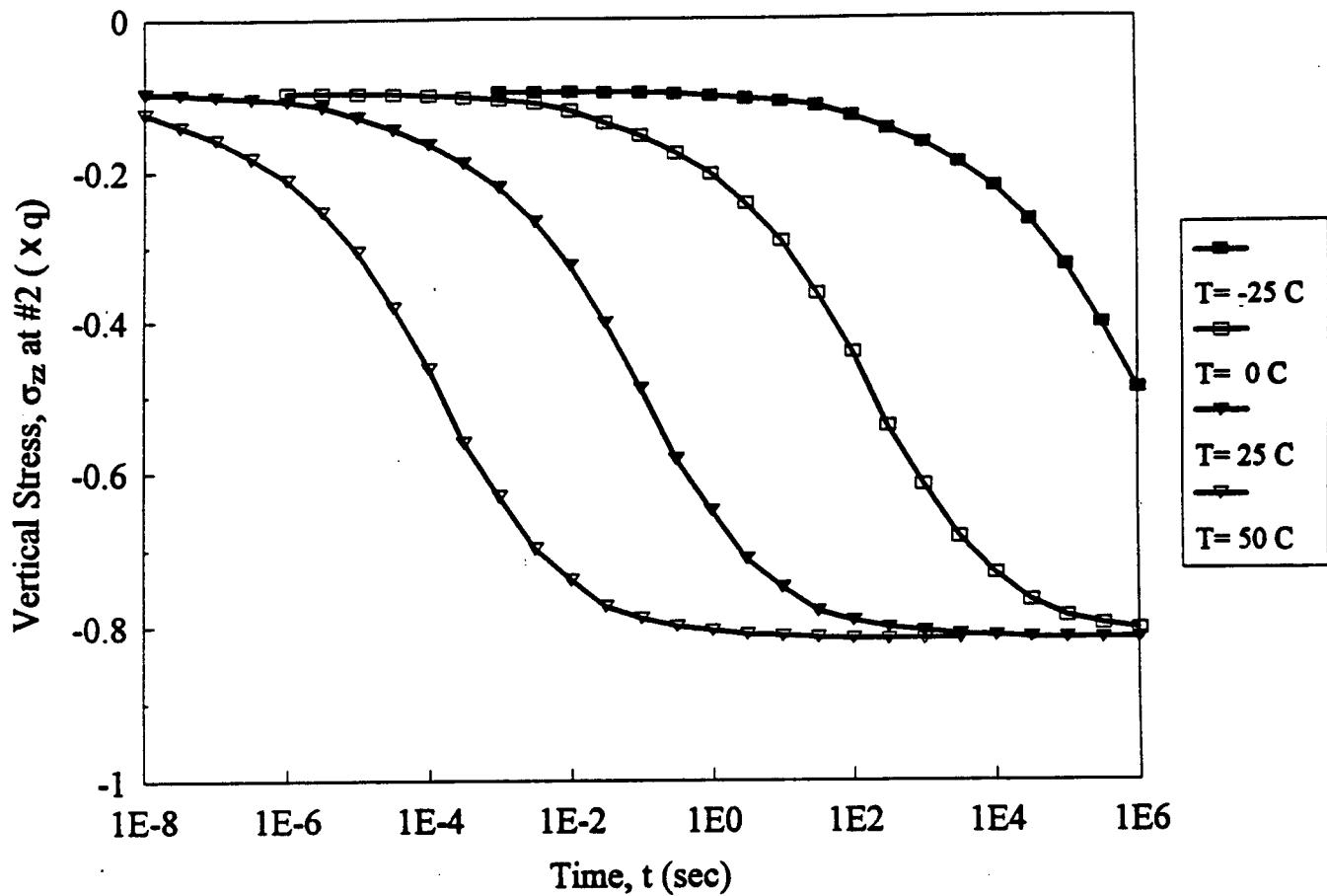


Fig. 14. Vertical stress at position #2 under constant load and constant temperatures (Case 1).

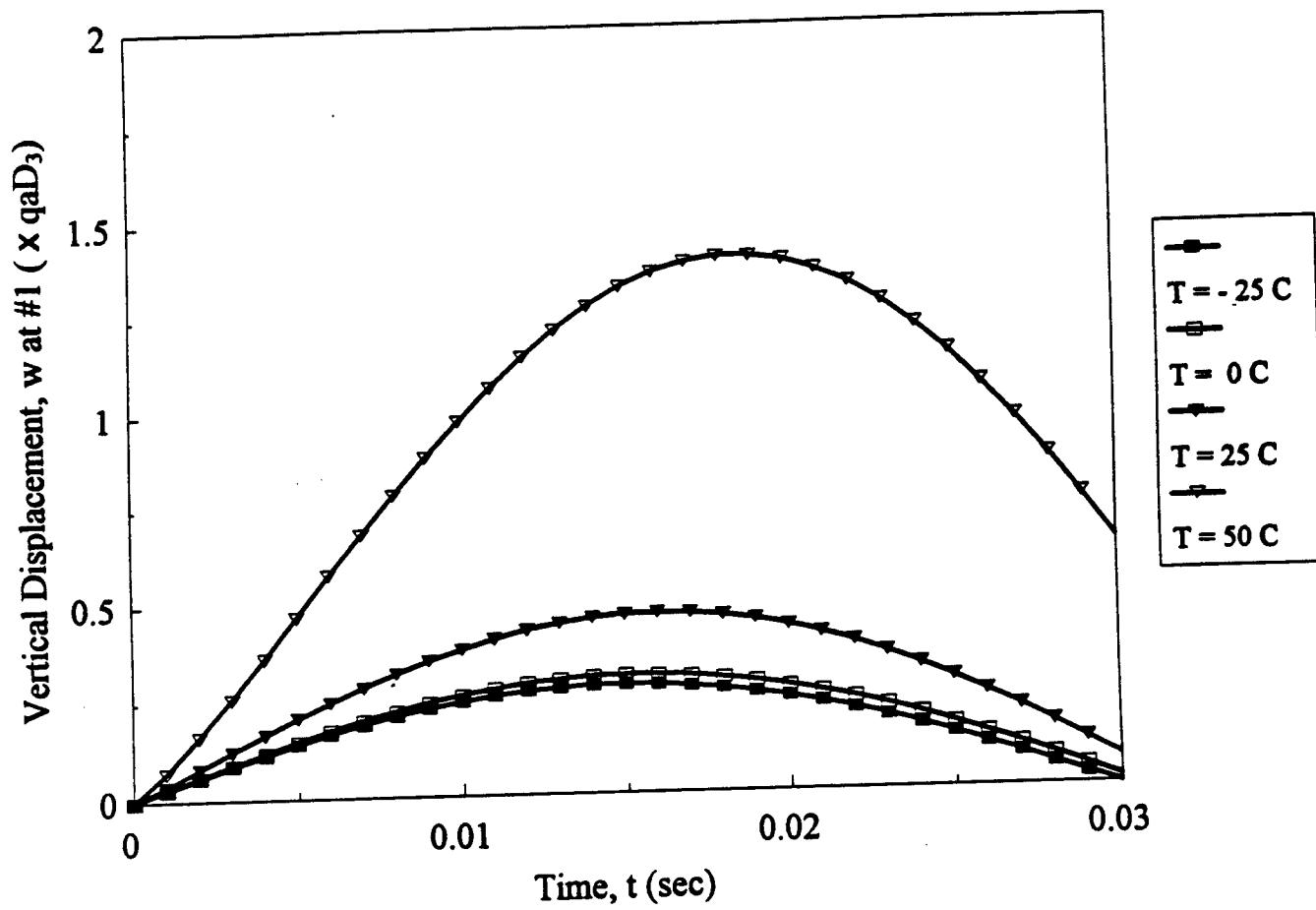


Fig. 15. Vertical displacement at position #1 under transient load and constant temperatures (Case 2).

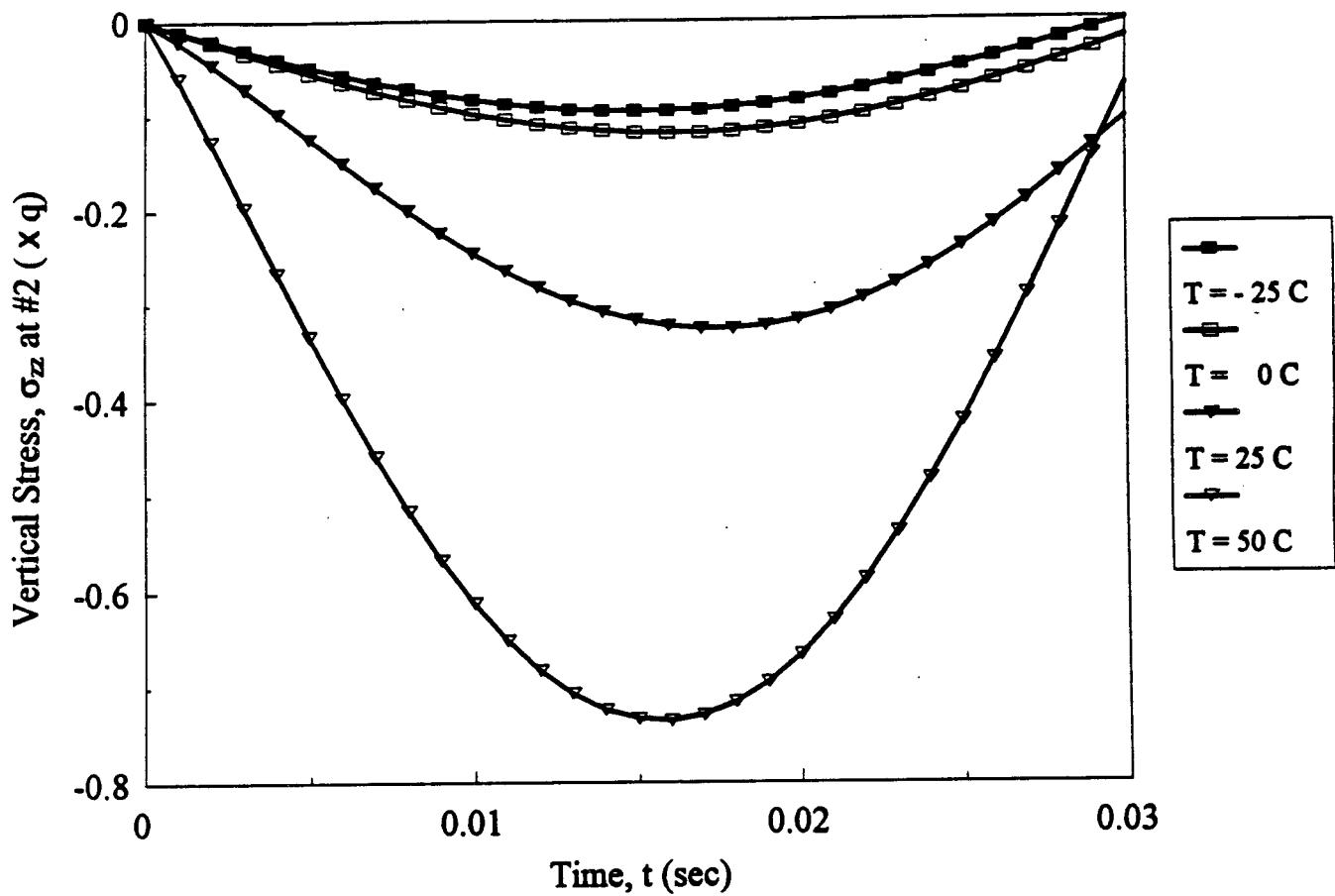


Fig. 16. Vertical stress at position #2 under transient load and constant temperatures (Case 2).

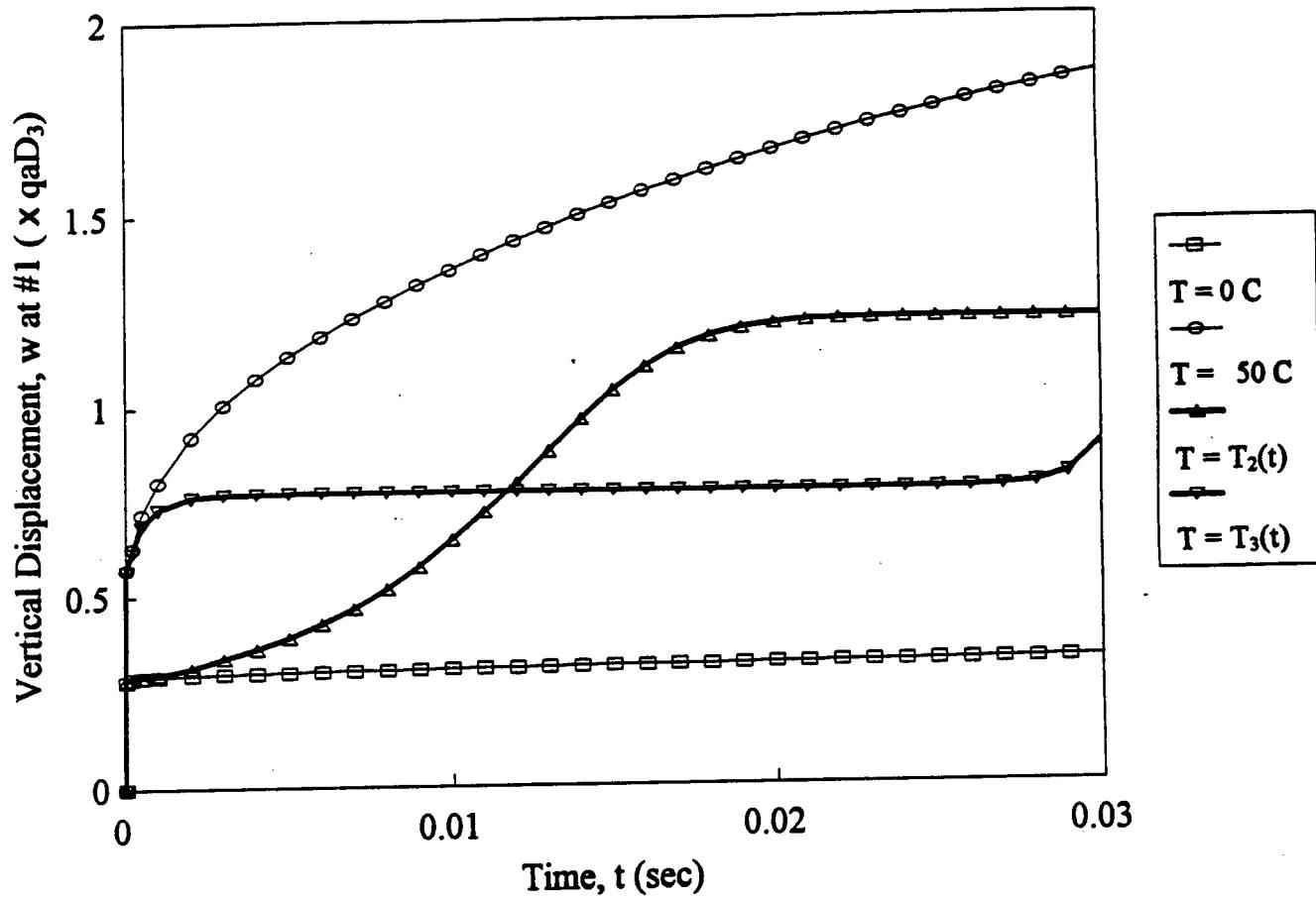


Fig. 17. Vertical displacement at position #1 under constant load and transient temperatures (Case 3).

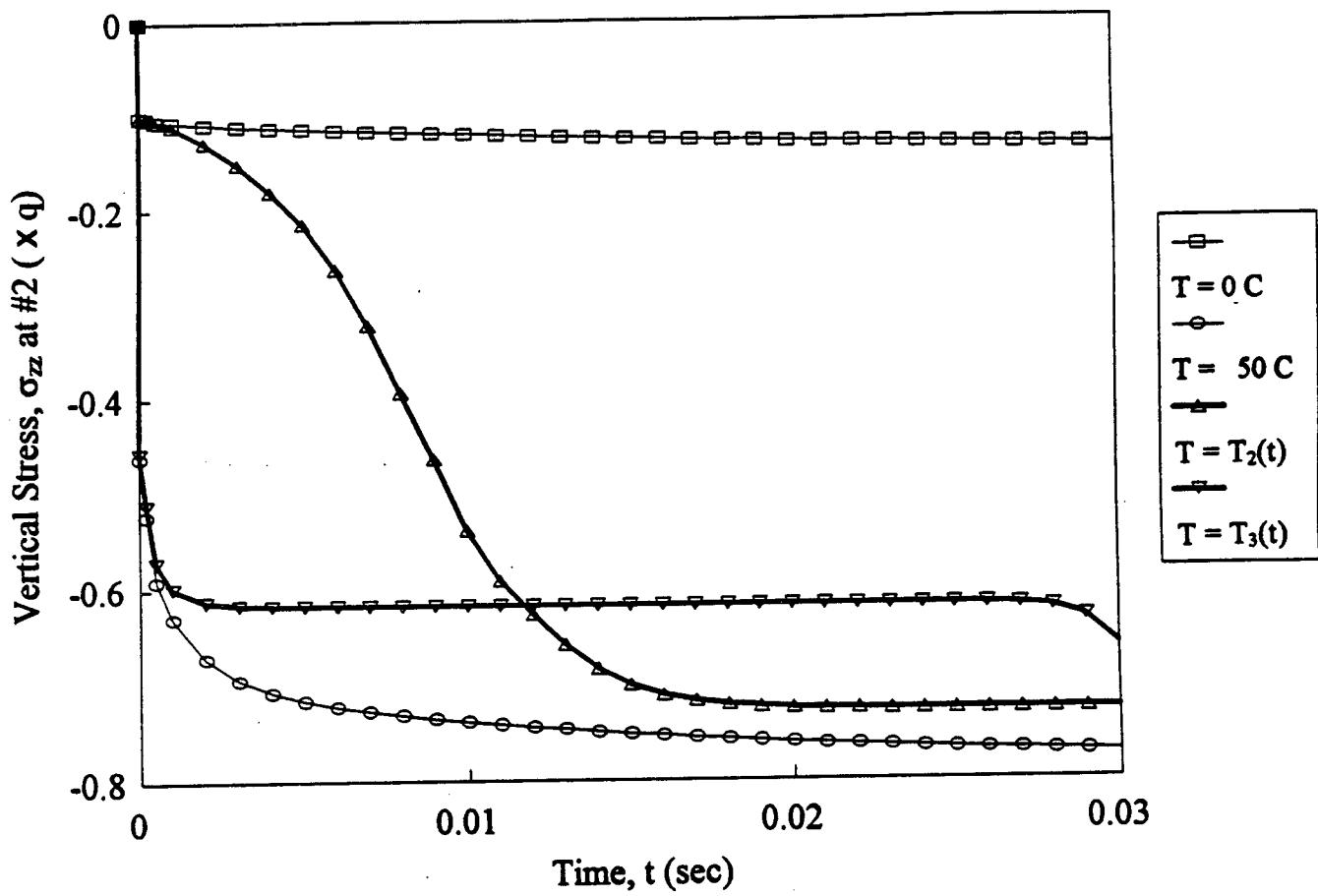


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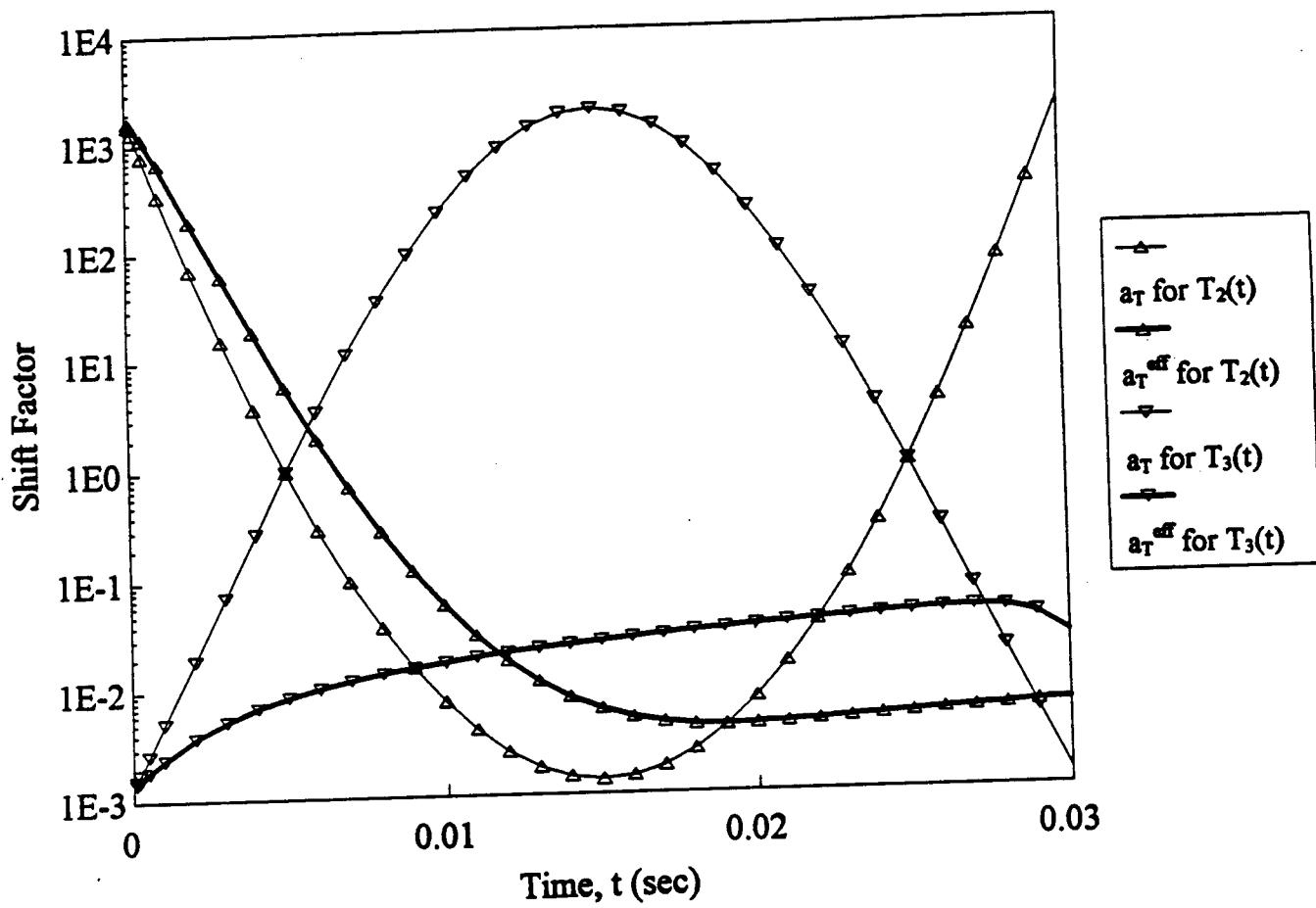


Fig. 19. Shift factors and effective shift factors for temperature histories $T_2(t)$ and $T_3(t)$.

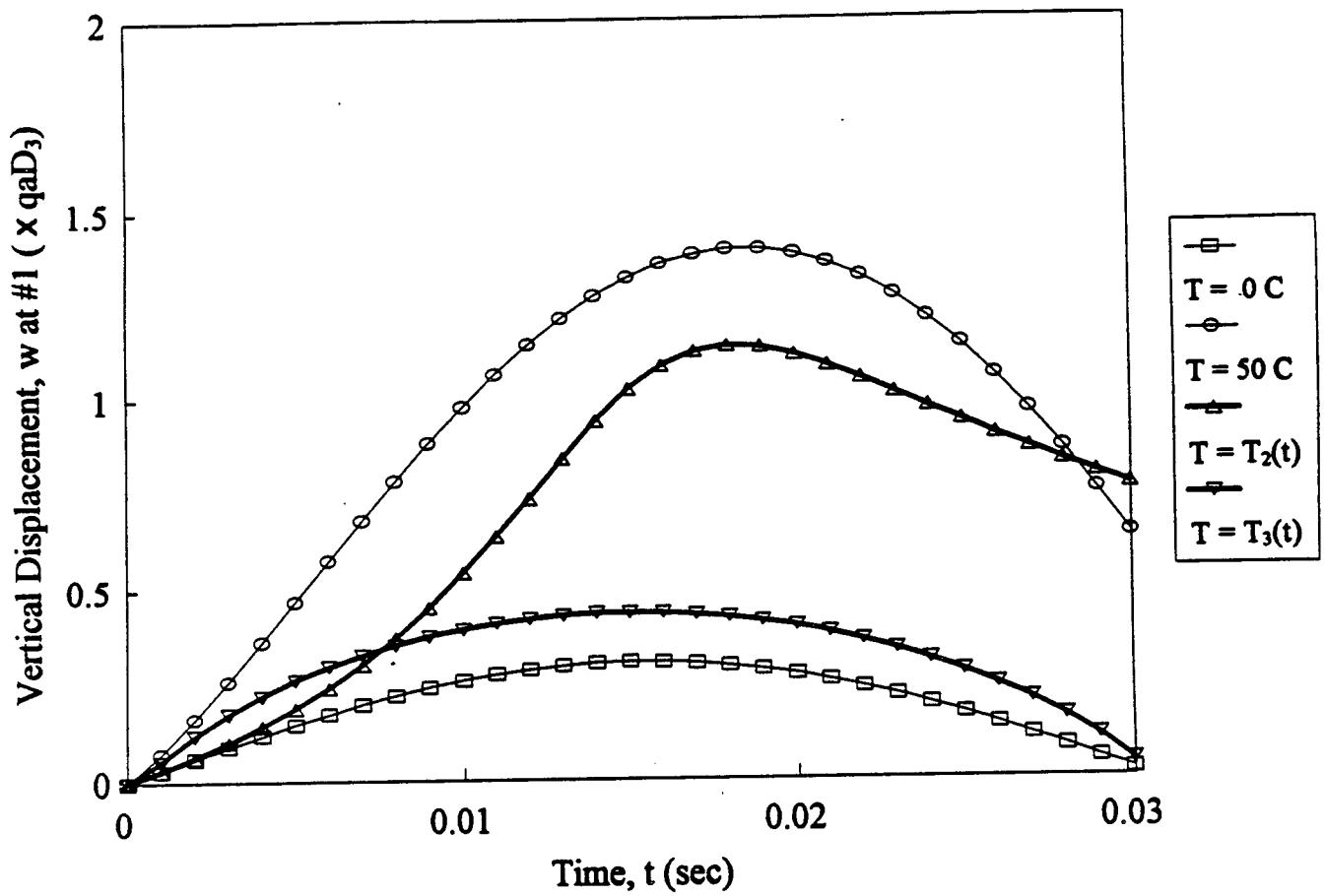


Fig. 20. Vertical displacement at position #1 under transient load and transient temperatures (Case 4).

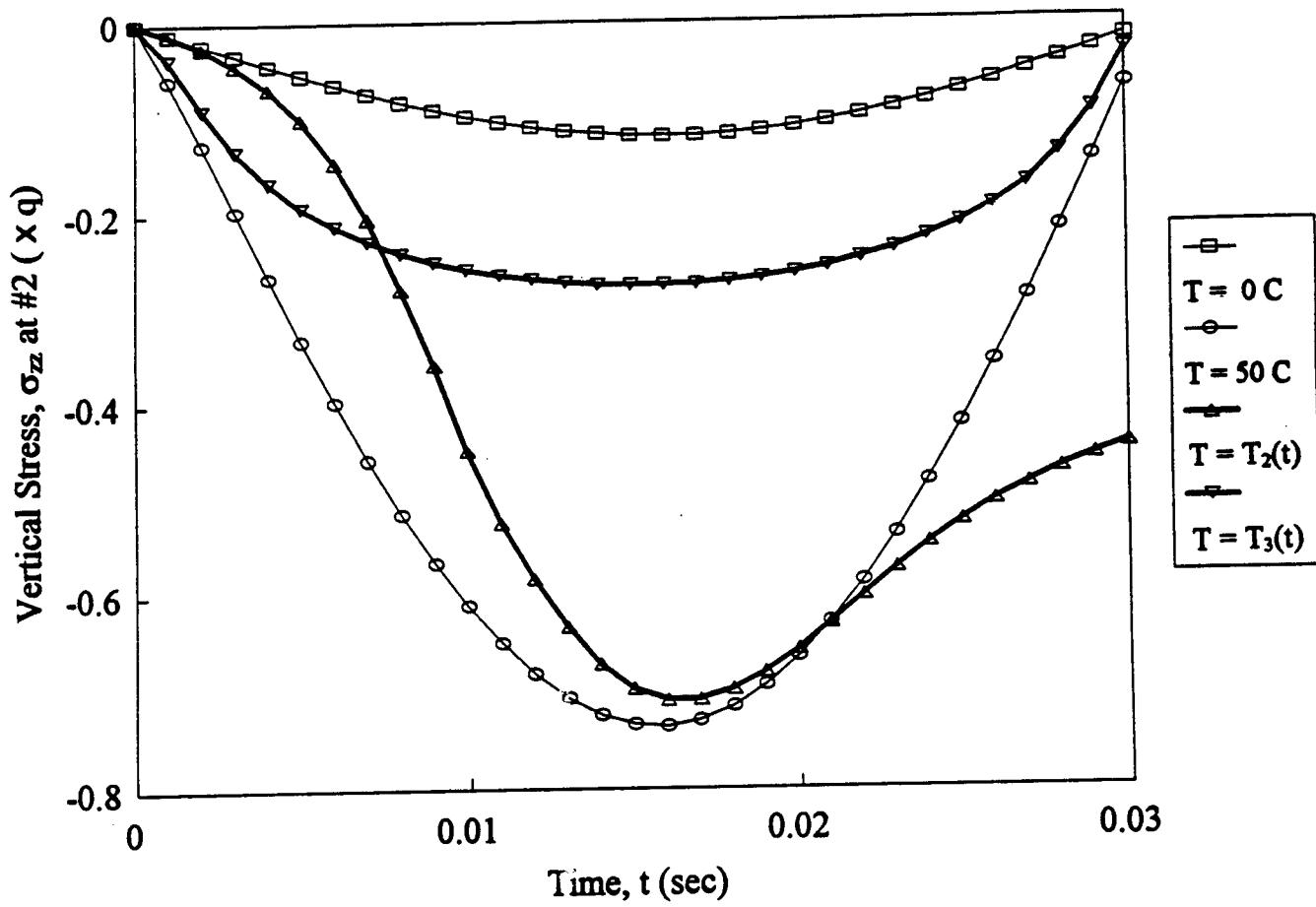


Fig. 21. Vertical stress at position #2 under transient load and transient temperatures (Case 4).

APPENDIX C

BACKCALCULATED AC MODULI AND CENTER PEAK DEFLECTIONS

(FOR P = 40 KN)

Backcalculated AC moduli and center peak deflections (for P = 40 kN).

I	J	K	(see legends on the bottom of table)	FWD Center Peak Deflection (mm)	Backcalculated AC Modulus (MPa)	Mid-Depth AC Temperature (C)	Thickness of AC Layer (mm)	Measurement Time of Day
1	1	1	1	0.37	2959	23.9	114	09:33 AM
1	1	1	2	0.335	3841	23.9	114	09:36 AM
1	1	1	3	0.363	2841	23.9	114	09:39 AM
1	1	1	4	0.385	2359	23.9	114	09:42 AM
1	1	2	1	0.4	2497	28.2	114	10:31 AM
1	1	2	2	0.349	3048	28.2	114	10:34 AM
1	1	2	3	0.39	2262	28.2	114	10:37 AM
1	1	2	4	0.401	2138	28.2	114	10:40 AM
1	1	3	1	0.408	1648	29.7	114	11:33 AM
1	1	3	2	0.388	2759	29.7	114	11:36 AM
1	1	3	3	0.391	2087	29.7	114	11:39 AM
1	1	3	4	0.41	2083	29.7	114	11:43 AM
1	1	4	1	0.426	1986	31.4	114	12:31 PM
1	1	4	2	0.379	2483	31.4	114	12:34 PM
1	1	4	3	0.406	1876	31.4	114	12:37 PM
1	1	4	4	0.434	1669	31.4	114	12:40 PM
1	1	5	1	0.42	2080	31.9	114	01:34 PM
1	1	5	2	0.382	2448	31.9	114	01:39 PM
1	1	5	3	0.408	1703	31.9	114	01:42 PM
1	1	5	4	0.441	1566	31.9	114	01:46 PM
1	1	6	1	0.427	2000	32.4	114	02:31 PM
1	1	6	2	0.39	2255	32.4	114	02:34 PM
1	1	6	3	0.415	1641	32.4	114	02:38 PM
1	1	6	4	0.441	1683	32.4	114	02:43 PM
1	1	7	1	0.383	2489	32.4	114	03:31 PM
1	1	7	2	0.391	2317	32.4	114	03:34 PM
1	1	7	3	0.405	1924	32.4	114	03:39 PM
1	1	7	4	0.444	1517	32.4	114	03:43 PM
1	1	2	1	0.446	1583	35.1	114	09:01 AM
1	2	1	2	0.44	1052	35.1	114	09:04 AM
1	2	1	3	0.414	1662	35.1	114	09:07 AM
1	2	1	4	0.438	1338	35.1	114	09:10 AM
1	2	2	1	0.468	1255	38.7	114	10:01 AM
1	2	2	2	0.451	1634	38.7	114	10:04 AM
1	2	2	3	0.44	1262	38.7	114	10:07 AM
1	2	2	4	0.453	1103	38.7	114	10:10 AM
1	2	3	1	0.504	959	43.7	114	11:04 AM
1	2	3	2	0.495	1172	43.7	114	11:07 AM
1	2	3	3	0.458	1041	43.7	114	11:10 AM
1	2	3	4	0.494	862	43.7	114	11:16 AM
1	2	4	1	0.52	860	46.3	114	12:16 PM
1	2	4	2	0.521	903	46.3	114	12:19 PM
1	2	4	3	0.47	938	46.3	114	12:22 PM
1	2	4	4	0.509	821	46.3	114	12:25 PM
1	2	5	1	0.538	869	48.4	114	01:01 PM
1	2	5	2	0.539	945	48.4	114	01:04 PM
1	2	5	3	0.491	903	48.4	114	01:07 PM
1	2	5	4	0.514	738	48.4	114	01:10 PM
1	2	6	1	0.534	860	50.1	114	02:16 PM
1	2	6	2	0.559	869	50.1	114	02:19 PM
1	2	6	3	0.507	752	50.1	114	02:22 PM
1	2	6	4	0.543	855	50.1	114	02:25 PM
1	2	7	1	0.54	793	49.9	114	03:03 PM
1	2	7	2	0.562	903	49.9	114	03:04 PM
1	2	7	3	0.514	766	49.9	114	03:07 PM
1	2	7	4	0.538	862	49.9	114	03:10 PM
1	2	8	1	0.536	883	49.3	114	04:04 PM
1	2	8	2	0.553	993	49.3	114	04:07 PM
1	2	8	3	0.496	924	49.3	114	04:10 PM
1	2	8	4	0.547	869	49.3	114	04:13 PM
1	3	1	1	0.312	6662	8.7	114	09:04 AM
1	3	1	2	0.245	10014	8.7	114	09:10 AM
1	3	1	3	0.283	7234	8.7	114	09:13 AM
1	3	1	4	0.306	5828	8.7	114	09:16 AM
1	3	2	1	0.323	6621	12.6	114	10:01 AM
1	3	2	2	0.249	9490	12.6	114	10:06 AM
1	3	2	3	0.301	6538	12.6	114	10:10 AM
1	3	2	4	0.315	5372	12.6	114	10:13 AM
1	3	3	1	0.332	6876	15.7	114	11:04 AM
1	3	3	2	0.268	7572	15.7	114	11:09 AM
1	3	3	3	0.315	5524	15.7	114	11:13 AM
1	3	3	4	0.334	4366	15.7	114	11:16 AM
1	3	4	1	0.33	6579	16.6	114	12:03 PM
1	3	4	2	0.28	6593	16.6	114	12:07 PM
1	3	4	3	0.332	4738	16.6	114	12:12 PM
1	3	4	4	0.347	4083	16.6	114	12:15 PM
1	3	5	1	0.345	6303	20.5	114	01:01 PM
1	3	5	2	0.29	6483	20.5	114	01:07 PM
1	3	5	3	0.345	4103	20.5	114	01:10 PM
1	3	5	4	0.359	3152	20.5	114	01:13 PM
1	3	6	1	0.355	6048	21.6	114	02:04 PM
1	3	6	2	0.295	6048	21.6	114	02:07 PM
1	3	6	3	0.337	4428	21.6	114	02:12 PM
1	3	6	4	0.361	2966	21.6	114	02:16 PM
1	3	7	1	0.35	6159	19.6	114	03:04 PM
1	3	7	2	0.284	6324	19.6	114	03:07 PM
1	3	7	3	0.326	5200	19.6	114	03:10 PM
1	3	7	4	0.347	3890	19.6	114	03:15 PM
1	3	8	1	0.345	6303	18.4	114	04:01 PM
1	3	8	2	0.281	7352	18.4	114	04:06 PM
1	3	8	3	0.323	5186	18.4	114	04:09 PM

1	3	8	4	0.338	3828	18.4	114	04:12 PM
1	4	1	1	0.308	8158	5.8	114	09:31 AM
1	4	1	2	0.253	10579	5.8	114	09:36 AM
1	4	1	3	0.302	7979	5.8	114	09:39 AM
1	4	1	4	0.313	7186	5.8	114	09:42 AM
1	4	2	1	0.322	7807	9.2	114	10:28 AM
1	4	2	2	0.263	9278	9.2	114	10:33 AM
1	4	2	3	0.311	8972	9.2	114	10:36 AM
1	4	2	4	0.321	8131	9.2	114	10:40 AM
1	4	3	1	0.337	6745	12.5	114	11:31 AM
1	4	3	2	0.277	8945	12.5	114	11:36 AM
1	4	3	3	0.322	6290	12.5	114	11:39 AM
1	4	3	4	0.343	5248	12.5	114	11:42 AM
1	4	4	1	0.352	8103	15	114	12:31 PM
1	4	4	2	0.287	7476	15	114	12:34 PM
1	4	4	3	0.339	5428	15	114	12:37 PM
1	4	4	4	0.351	5228	15	114	12:40 PM
1	4	5	1	0.365	6062	16.9	114	01:31 PM
1	4	5	2	0.301	6834	16.9	114	01:34 PM
1	4	5	3	0.349	4952	16.9	114	01:37 PM
1	4	5	4	0.367	4386	16.9	114	01:42 PM
1	4	6	1	0.375	5559	17.6	114	02:31 PM
1	4	6	2	0.306	8400	17.6	114	02:34 PM
1	4	6	3	0.351	4821	17.6	114	02:37 PM
1	4	6	4	0.371	4228	17.6	114	02:42 PM
1	4	7	1	0.359	6966	15.3	114	03:31 PM
1	4	7	2	0.291	7807	15.3	114	03:34 PM
1	4	7	3	0.344	5476	15.3	114	03:37 PM
1	4	7	4	0.356	4979	15.3	114	03:40 PM
2	1	1	1	0.277	5834	21.1	229	08:42 AM
2	1	1	2	0.286	5766	21.1	229	08:45 AM
2	1	1	3	0.264	6503	21.1	229	08:51 AM
2	1	1	4	0.304	4848	21.1	229	08:54 AM
2	1	2	1	0.271	5841	21.4	229	09:33 AM
2	1	2	2	0.287	5703	21.4	229	09:36 AM
2	1	2	3	0.278	5800	21.4	229	09:40 AM
2	1	2	4	0.297	4867	21.4	229	09:43 AM
2	1	3	1	0.294	4779	22.2	229	10:34 AM
2	1	3	2	0.302	5041	22.2	229	10:37 AM
2	1	3	3	0.283	5428	22.2	229	10:40 AM
2	1	3	4	0.305	4703	22.2	229	10:43 AM
2	1	4	1	0.307	4745	23.4	229	11:31 AM
2	1	4	2	0.288	5310	23.4	229	11:34 AM
2	1	4	3	0.31	4497	23.4	229	11:37 AM
2	1	4	4	0.314	4379	23.4	229	11:43 AM
2	1	5	1	0.289	4807	25.3	229	12:31 PM
2	1	5	2	0.318	4462	25.3	229	12:34 PM
2	1	5	3	0.295	5041	25.3	229	12:37 PM
2	1	5	4	0.317	4288	25.3	229	12:40 PM
2	1	6	1	0.296	4579	26.4	229	01:31 PM
2	1	6	2	0.307	4766	26.4	229	01:36 PM
2	1	6	3	0.293	5028	26.4	229	01:39 PM
2	1	6	4	0.324	4076	26.4	229	01:42 PM
2	1	7	1	0.311	4138	26.8	229	02:31 PM
2	1	7	2	0.318	4331	26.8	229	02:36 PM
2	1	7	3	0.304	4759	26.8	229	02:39 PM
2	1	7	4	0.332	3800	26.8	229	02:43 PM
2	1	8	1	0.3	4428	28	229	03:37 PM
2	1	8	2	0.318	4324	28	229	03:40 PM
2	1	8	3	0.305	4628	28	229	03:43 PM
2	1	8	4	0.336	3876	28	229	03:46 PM
2	2	1	1	0.341	2768	34.6	229	08:34 AM
2	2	1	2	0.343	2841	34.6	229	08:37 AM
2	2	1	3	0.339	2917	34.6	229	08:40 AM
2	2	2	1	0.367	2531	34.6	229	08:43 AM
2	2	2	2	0.336	2786	35.7	229	09:33 AM
2	2	2	3	0.354	2855	35.7	229	09:36 AM
2	2	2	4	0.344	2786	35.7	229	09:39 AM
2	2	2	5	0.378	2303	35.7	229	09:42 AM
2	2	2	6	0.349	2499	37.6	229	10:36 AM
2	2	2	7	0.378	2269	37.6	229	10:39 AM
2	2	2	8	0.376	2283	37.6	229	10:42 AM
2	2	3	4	0.396	1924	37.6	229	10:43 AM
2	2	4	1	0.37	2138	40	229	11:34 AM
2	2	4	2	0.401	1945	40	229	11:37 AM
2	2	4	3	0.404	1890	40	229	11:43 AM
2	2	4	4	0.430	1563	40	229	11:45 AM
2	2	5	1	0.401	1779	43.6	229	12:36 PM
2	2	5	2	0.439	1572	43.6	229	12:37 PM
2	2	5	3	0.431	1841	43.6	229	12:40 PM
2	2	5	4	0.473	1303	43.6	229	12:43 PM
2	2	6	1	0.423	1572	44.7	229	01:33 PM
2	2	6	2	0.461	1407	44.7	229	01:36 PM
2	2	6	3	0.452	1441	44.7	229	01:39 PM
2	2	6	4	0.497	1172	44.7	229	01:42 PM
2	2	7	1	0.437	1455	46	229	02:34 PM
2	2	7	2	0.451	1434	46	229	02:37 PM
2	2	7	3	0.454	1414	46	229	02:39 PM
2	2	7	4	0.51	1138	46	229	02:42 PM
2	2	8	1	0.451	1352	47.1	229	03:31 PM
2	2	8	2	0.454	1434	47.1	229	03:34 PM
2	2	8	3	0.449	1476	47.1	229	03:37 PM
2	2	8	4	0.513	1110	47.1	229	03:40 PM
2	2	9	1	0.45	1366	47.8	229	04:27 PM
2	2	9	2	0.452	1455	47.8	229	04:30 PM
2	2	9	3	0.451	1428	47.8	229	04:33 PM
2	2	9	4	0.5	1166	47.8	229	04:36 PM

2	3	1	1	1	0.264	6807	15.4	229	08:18 AM
2	3	1	1	2	0.272	6917	15.4	229	08:21 AM
2	3	1	1	3	0.26	7482	15.4	229	08:24 AM
2	3	1	1	4	0.29	6021	15.4	229	08:28 AM
2	3	1	2	1	0.283	6572	16	229	10:16 AM
2	3	2	2	2	0.262	7080	16	229	10:19 AM
2	3	2	2	3	0.262	7280	16	229	10:22 AM
2	3	2	2	4	0.287	5959	16	229	10:27 AM
2	3	3	1	1	0.273	5917	16.8	229	11:16 AM
2	3	3	2	2	0.279	6331	16.8	229	11:21 AM
2	3	3	3	3	0.265	7200	16.8	229	11:25 AM
2	3	3	4	4	0.289	5903	16.8	229	11:30 AM
2	3	4	1	1	0.281	5855	17.2	229	12:19 PM
2	3	4	2	2	0.27	6703	17.2	229	12:24 PM
2	3	4	3	3	0.264	7152	17.2	229	12:27 PM
2	3	4	4	4	0.283	5724	17.2	229	12:31 PM
2	3	5	1	1	0.271	5890	17.7	229	01:16 PM
2	3	5	2	2	0.278	6352	17.7	229	01:21 PM
2	3	5	3	3	0.269	6986	17.7	229	01:25 PM
2	3	5	4	4	0.296	5434	17.7	229	01:30 PM
2	3	6	1	1	0.272	5855	18.2	229	02:16 PM
2	3	6	2	2	0.276	6531	18.2	229	02:19 PM
2	3	6	3	3	0.272	6750	18.2	229	02:24 PM
2	3	6	4	4	0.288	5372	18.2	229	02:27 PM
2	3	7	1	1	0.272	5834	18.4	229	03:18 PM
2	3	7	2	2	0.276	6648	18.4	229	03:22 PM
2	3	7	3	3	0.27	6848	18.4	229	03:25 PM
2	3	7	4	4	0.296	5517	18.4	229	03:28 PM
2	3	8	1	1	0.272	5072	18.8	229	04:19 PM
2	3	8	2	2	0.27	6814	18.8	229	04:22 PM
2	3	8	3	3	0.269	6860	18.8	229	04:27 PM
2	3	8	4	4	0.296	5510	18.8	229	04:31 PM
2	4	1	1	1	0.234	10359	5.9	229	08:46 AM
2	4	1	1	2	0.239	11221	5.9	229	08:49 AM
2	4	1	1	3	0.228	11931	5.9	229	08:52 AM
2	4	1	4	4	0.257	9324	5.9	229	08:55 AM
2	4	2	1	1	0.237	10097	6.7	229	09:48 AM
2	4	2	2	2	0.249	10078	6.7	229	09:52 AM
2	4	2	3	3	0.235	11262	6.7	229	09:55 AM
2	4	2	4	4	0.258	9069	6.7	229	09:58 AM
2	4	3	1	1	0.248	9028	9.5	229	10:49 AM
2	4	3	2	2	0.256	9366	9.5	229	10:52 AM
2	4	3	3	3	0.241	10945	9.5	229	10:55 AM
2	4	3	4	4	0.257	9255	9.5	229	10:58 AM
2	4	4	1	1	0.261	8276	10.7	229	11:40 AM
2	4	4	2	2	0.267	8579	10.7	229	11:52 AM
2	4	4	3	3	0.247	10814	10.7	229	11:55 AM
2	4	4	4	4	0.265	8614	10.7	229	11:58 AM
2	4	5	1	1	0.269	7572	11.1	229	01:06 PM
2	4	5	2	2	0.272	8297	11.1	229	01:10 PM
2	4	5	3	3	0.251	10028	11.1	229	01:13 PM
2	4	5	4	4	0.271	8255	11.1	229	01:16 PM
2	4	6	1	1	0.268	7621	11.7	229	01:49 PM
2	4	6	2	2	0.267	8634	11.7	229	01:52 PM
2	4	6	3	3	0.246	10166	11.7	229	01:55 PM
2	4	6	4	4	0.273	8097	11.7	229	01:58 PM
2	4	7	1	1	0.273	7248	12.4	229	02:49 PM
2	4	7	2	2	0.278	7803	12.4	229	02:52 PM
2	4	7	3	3	0.248	9889	12.4	229	02:55 PM
2	4	7	4	4	0.279	7768	12.4	229	02:58 PM
2	4	8	1	1	0.264	7759	12.7	229	03:51 PM
2	4	8	2	2	0.268	8441	12.7	229	03:54 PM
2	4	8	3	3	0.255	9338	12.7	229	03:57 PM
2	4	8	4	4	0.275	7003	12.7	229	04:01 PM
3	1	1	1	1	0.18	5710	21.2	305	08:43 AM
3	1	1	1	2	0.158	6434	21.2	305	08:48 AM
3	1	1	1	3	0.150	8083	21.2	305	08:51 AM
3	1	1	1	4	0.165	8000	21.2	305	08:54 AM
3	1	1	2	1	0.179	6152	21.9	305	08:33 AM
3	1	1	2	2	0.16	6386	21.9	305	08:36 AM
3	1	1	2	3	0.166	7363	21.9	305	08:40 AM
3	1	1	2	4	0.17	7310	21.9	305	08:43 AM
3	1	1	3	1	0.193	5434	23.6	305	10:33 AM
3	1	1	3	2	0.172	5303	23.6	305	10:36 AM
3	1	1	3	3	0.176	6697	23.6	305	10:39 AM
3	1	1	3	4	0.188	5659	23.6	305	10:42 AM
3	1	1	4	1	0.212	4097	25.7	305	11:34 AM
3	1	1	4	2	0.182	4648	25.7	305	11:37 AM
3	1	1	4	3	0.181	6428	25.7	305	11:40 AM
3	1	1	4	4	0.198	5290	25.7	305	11:45 AM
3	1	1	5	1	0.217	4124	27.6	305	12:33 PM
3	1	1	5	2	0.198	4131	27.6	305	12:37 PM
3	1	1	5	3	0.203	5186	27.6	305	12:40 PM
3	1	1	5	4	0.213	4572	27.6	305	12:43 PM
3	1	1	6	1	0.228	3772	29.1	305	01:34 PM
3	1	1	6	2	0.212	3828	29.1	305	01:37 PM
3	1	1	6	3	0.212	4579	29.1	305	01:42 PM
3	1	1	6	4	0.223	4021	29.1	305	01:45 PM
3	1	1	7	1	0.238	3434	30.4	305	02:33 PM
3	1	1	7	2	0.213	3388	30.4	305	02:34 PM
3	1	1	7	3	0.207	4752	30.4	305	02:39 PM
3	1	1	7	4	0.216	4262	30.4	305	02:42 PM
3	1	1	8	1	0.241	3183	32	305	03:33 PM
3	1	1	8	2	0.208	3517	32	305	03:36 PM
3	1	1	8	3	0.215	4359	32	305	03:40 PM
3	1	1	8	4	0.222	4089	32	305	03:43 PM
3	1	2	1	1	0.258	2710	33	305	09:10 AM

3	2	1	2	0.22	2903	33	305	09:13 AM
3	2	1	3	0.234	3510	33	305	09:16 AM
3	2	1	4	0.238	3338	33	305	09:19 AM
3	2	2	1	0.257	2641	33.7	305	10:03 AM
3	2	2	2	0.227	2738	33.7	305	10:06 AM
3	2	2	3	0.237	3434	33.7	305	10:09 AM
3	2	2	4	0.242	3269	33.7	305	10:10 AM
3	2	3	1	0.261	2538	34.8	305	11:04 AM
3	2	3	2	0.237	2503	34.8	305	11:07 AM
3	2	3	3	0.25	3083	34.8	305	11:10 AM
3	2	3	4	0.256	2862	34.8	305	11:13 AM
3	2	4	1	0.285	2214	36.6	305	12:04 PM
3	2	4	2	0.253	2152	36.6	305	12:07 PM
3	2	4	3	0.27	2669	36.6	305	12:10 PM
3	2	4	4	0.27	2524	36.6	305	12:13 PM
3	2	5	1	0.283	2269	38.5	305	01:03 PM
3	2	5	2	0.272	1910	38.5	305	01:07 PM
3	2	5	3	0.295	2166	38.5	305	01:09 PM
3	2	5	4	0.288	2214	38.5	305	01:12 PM
3	2	6	1	0.283	1993	40.6	305	02:04 PM
3	2	6	2	0.287	1862	40.6	305	02:07 PM
3	2	6	3	0.305	2007	40.6	305	02:10 PM
3	2	6	4	0.313	1821	40.6	305	02:13 PM
3	2	7	1	0.308	1862	42.3	305	03:04 PM
3	2	7	2	0.289	1614	42.3	305	03:07 PM
3	2	7	3	0.3	1986	42.3	305	03:10 PM
3	2	7	4	0.309	1848	42.3	305	03:13 PM
3	2	8	1	0.308	1883	42.6	305	04:03 PM
3	2	8	2	0.288	1600	42.6	305	04:06 PM
3	2	8	3	0.305	1897	42.6	305	04:09 PM
3	2	8	4	0.307	1862	42.6	305	04:12 PM
3	3	1	1	0.158	9055	15.5	305	09:34 AM
3	3	1	2	0.143	9524	15.5	305	09:39 AM
3	3	1	3	0.146	11234	15.5	305	09:43 AM
3	3	1	4	0.15	11290	15.5	305	09:46 AM
3	3	2	1	0.161	8559	16.3	305	10:31 AM
3	3	2	2	0.15	8414	16.3	305	10:36 AM
3	3	2	3	0.148	10703	16.3	305	10:40 AM
3	3	2	4	0.152	10372	16.3	305	10:43 AM
3	3	3	1	0.189	7024	18.1	305	11:31 AM
3	3	3	2	0.154	7841	18.1	305	11:38 AM
3	3	3	3	0.152	10860	18.1	305	11:39 AM
3	3	3	4	0.158	9259	18.1	305	11:43 AM
3	3	4	1	0.172	7317	19.1	305	12:31 PM
3	3	4	2	0.158	7303	19.1	305	12:34 PM
3	3	4	3	0.158	10159	19.1	305	12:37 PM
3	3	4	4	0.165	8524	19.1	305	12:42 PM
3	3	5	1	0.177	7269	20.8	305	01:34 PM
3	3	5	2	0.182	7021	20.8	305	01:37 PM
3	3	5	3	0.16	9372	20.8	305	01:40 PM
3	3	5	4	0.160	8179	20.8	305	01:45 PM
3	3	6	1	0.177	7076	21.6	305	02:31 PM
3	3	6	2	0.165	6568	21.6	305	02:34 PM
3	3	6	3	0.161	9345	21.6	305	02:38 PM
3	3	6	4	0.168	7824	21.6	305	02:42 PM
3	3	7	1	0.176	7062	22.1	305	03:33 PM
3	3	7	2	0.163	6779	22.1	305	03:36 PM
3	3	7	3	0.162	8090	22.1	305	03:39 PM
3	3	7	4	0.160	7710	22.1	305	03:43 PM
3	4	1	1	0.129	13793	7	305	09:13 AM
3	4	1	2	0.121	13793	7	305	09:16 AM
3	4	1	3	0.118	13793	7	305	09:19 AM
3	4	1	4	0.122	13793	7	305	09:22 AM
3	4	2	1	0.134	13669	7.3	305	10:04 AM
3	4	2	2	0.123	13793	7.3	305	10:07 AM
3	4	2	3	0.121	13793	7.3	305	10:10 AM
3	4	2	4	0.126	13793	7.3	305	10:13 AM
3	4	3	1	0.136	13634	8.5	305	11:03 AM
3	4	3	2	0.128	12993	8.5	305	11:06 AM
3	4	3	3	0.126	13793	8.5	305	11:09 AM
3	4	3	4	0.133	13793	8.5	305	11:13 AM
3	4	4	1	0.144	12317	10.4	305	12:03 PM
3	4	4	2	0.134	11860	10.4	305	12:06 PM
3	4	4	3	0.129	13793	10.4	305	12:10 PM
3	4	4	4	0.138	13772	10.4	305	12:13 PM
3	4	5	1	0.149	11524	12.4	305	01:01 PM
3	4	5	2	0.139	10841	12.4	305	01:04 PM
3	4	5	3	0.134	13793	12.4	305	01:07 PM
3	4	5	4	0.146	11828	12.4	305	01:10 PM
3	4	6	1	0.156	10372	14.3	305	02:04 PM
3	4	6	2	0.145	8510	14.3	305	02:07 PM
3	4	6	3	0.141	13497	14.3	305	02:10 PM
3	4	6	4	0.153	10800	14.3	305	02:13 PM
3	4	7	1	0.16	9834	14.9	305	03:03 PM
3	4	7	2	0.147	9441	14.9	305	03:04 PM
3	4	7	3	0.143	13131	14.9	305	03:09 PM
3	4	7	4	0.153	10807	14.9	305	03:13 PM
3	4	8	1	0.16	9559	16.5	305	04:01 PM
3	4	8	2	0.149	9097	16.5	305	04:04 PM
3	4	8	3	0.142	13572	16.5	305	04:07 PM
3	4	8	4	0.153	10528	16.5	305	04:10 PM
4	1	1	1	0.232	6786	15	254	09:40 AM
4	1	1	2	0.202	9552	15	254	09:45 AM
4	1	1	3	0.178	8345	15	254	09:48 AM
4	1	1	4	0.166	5400	15	254	09:52 AM
4	1	2	1	0.245	6310	16.2	254	10:33 AM
4	1	2	2	0.211	8834	16.2	254	10:37 AM

4	1	2	3	4	0.185	7724	18.2	254	10:40 AM
4	1	3	2	1	0.173	4800	18.2	254	10:45 AM
4	1	3	3	2	0.254	5731	18.9	254	11:34 AM
4	1	3	3	3	0.22	8048	18.9	254	11:37 AM
4	1	3	4	4	0.19	7331	18.9	254	11:42 AM
4	1	3	4	1	0.176	4510	18.9	254	11:46 AM
4	1	4	2	2	0.263	5414	18.7	254	12:31 PM
4	1	4	4	4	0.229	7421	18.7	254	12:37 PM
4	1	4	5	1	0.2	8510	18.7	254	12:40 PM
4	1	5	5	2	0.186	4183	18.7	254	12:45 PM
4	1	5	5	3	0.276	4897	19.7	254	01:33 PM
4	1	5	5	4	0.233	8938	19.7	254	01:37 PM
4	1	5	6	1	0.207	6048	19.7	254	01:40 PM
4	1	5	6	2	0.194	3876	19.7	254	01:43 PM
4	1	5	6	3	0.289	4552	20.3	254	02:33 PM
4	1	6	6	2	0.25	8379	20.3	254	02:36 PM
4	1	6	6	3	0.212	5710	20.3	254	02:40 PM
4	1	6	7	1	0.202	3503	20.3	254	02:43 PM
4	1	6	7	2	0.268	4221	21.2	254	03:31 PM
4	1	6	7	3	0.254	5017	21.2	254	03:36 PM
4	1	6	7	4	0.217	5263	21.2	254	03:40 PM
4	1	6	7	5	0.21	3179	21.2	254	03:43 PM
4	1	6	7	6	0.637	1007	34.6	254	09:04 AM
4	2	1	1	1	0.535	1490	34.6	254	09:07 AM
4	2	1	1	2	0.45	1455	34.6	254	09:10 AM
4	2	1	1	3	0.523	641	34.6	254	09:13 AM
4	2	2	1	1	0.721	807	36.1	254	10:06 AM
4	2	2	2	2	0.611	1172	36.1	254	10:10 AM
4	2	2	2	3	0.507	1172	36.1	254	10:13 AM
4	2	2	2	4	0.579	538	36.1	254	10:16 AM
4	2	3	3	1	0.819	841	37.9	254	11:06 AM
4	2	3	3	2	0.686	938	37.9	254	11:09 AM
4	2	3	3	3	0.582	959	37.9	254	11:12 AM
4	2	3	3	4	0.636	455	37.9	254	11:15 AM
4	2	4	4	1	0.901	531	39.9	254	12:04 PM
4	2	4	4	2	0.77	752	39.9	254	12:07 PM
4	2	4	4	3	0.645	738	39.9	254	12:10 PM
4	2	4	4	4	0.707	379	39.9	254	12:13 PM
4	2	5	5	1	1.007	434	41.9	254	01:04 PM
4	2	5	5	2	0.850	614	41.9	254	01:07 PM
4	2	5	5	3	0.702	628	41.9	254	01:10 PM
4	2	5	6	4	0.776	345	41.9	254	01:13 PM
4	2	6	6	1	1.124	352	44	254	02:06 PM
4	2	6	6	2	0.954	503	44	254	02:09 PM
4	2	6	6	3	0.794	497	44	254	02:12 PM
4	2	6	6	4	0.856	345	44	254	02:15 PM
4	2	7	7	1	1.12	352	45.4	254	03:07 PM
4	2	7	7	2	0.958	490	45.4	254	03:10 PM
4	2	7	7	3	0.81	469	45.4	254	03:13 PM
4	2	7	7	4	0.905	345	45.4	254	03:16 PM
4	2	8	8	1	1.187	345	46.1	254	04:01 PM
4	2	8	8	2	1.02	441	46.1	254	04:04 PM
4	2	8	8	3	0.653	434	46.1	254	04:06 PM
4	2	8	8	4	0.94	345	46.1	254	04:09 PM
4	3	1	1	1	0.185	9745	9.5	254	09:51 AM
4	3	1	1	2	0.183	13124	9.5	254	09:55 AM
4	3	1	1	3	0.146	11014	9.5	254	10:00 AM
4	3	1	1	4	0.128	7883	9.5	254	10:04 AM
4	3	2	2	1	0.193	9080	10.4	254	10:46 AM
4	3	2	2	2	0.175	11579	10.4	254	10:51 AM
4	3	2	2	3	0.153	10262	10.4	254	10:54 AM
4	3	2	2	4	0.136	7124	10.4	254	10:57 AM
4	3	3	3	1	0.21	7772	11.9	254	11:48 AM
4	3	3	3	2	0.186	10366	11.9	254	11:52 AM
4	3	3	3	3	0.162	8979	11.9	254	11:55 AM
4	3	3	4	4	0.144	5050	11.9	254	11:58 AM
4	3	4	4	1	0.22	7145	13	254	12:46 PM
4	3	4	4	2	0.19	9448	13	254	12:51 PM
4	3	4	4	3	0.17	7979	13	254	12:55 PM
4	3	4	4	4	0.15	5248	13	254	12:58 PM
4	3	5	5	1	0.227	6848	14.6	254	01:46 PM
4	3	5	5	2	0.201	6828	14.6	254	01:51 PM
4	3	5	5	3	0.175	7531	14.6	254	01:54 PM
4	3	5	5	4	0.149	5379	14.6	254	01:57 PM
4	3	6	6	1	0.223	6821	16.1	254	02:46 PM
4	3	6	6	2	0.198	8972	16.1	254	02:51 PM
4	3	6	6	3	0.174	7648	16.1	254	03:00 PM
4	3	6	6	4	0.155	5145	18.1	254	03:03 PM
4	3	7	7	1	0.218	7214	18	254	04:01 PM
4	3	7	7	2	0.191	9800	18	254	04:04 PM
4	3	7	7	3	0.17	7952	18	254	04:09 PM
4	3	7	7	4	0.153	5221	18	254	04:12 PM
4	4	1	1	1	0.151	13793	2.5	254	09:37 AM
4	4	1	1	2	0.136	13793	2.5	254	09:40 AM
4	4	1	1	3	0.125	13793	2.5	254	09:43 AM
4	4	1	1	4	0.112	10959	2.5	254	09:48 AM
4	4	2	2	1	0.158	13752	3.9	254	10:34 AM
4	4	2	2	2	0.144	13793	3.9	254	10:37 AM
4	4	2	2	3	0.113	13793	3.9	254	10:40 AM
4	4	2	2	4	0.117	9859	3.9	254	10:43 AM
4	4	3	3	1	0.166	12276	4.3	254	11:36 AM
4	4	3	3	2	0.149	13793	4.3	254	11:39 AM
4	4	3	3	3	0.137	12988	4.3	254	11:43 AM
4	4	3	3	4	0.119	9448	4.3	254	11:46 AM
4	4	4	4	1	0.176	11262	5.4	254	12:34 PM
4	4	4	4	2	0.158	13372	5.4	254	12:37 PM
4	4	4	4	3	0.141	12407	5.4	254	12:40 PM

4	4	4	4	4	0.125	8593	5.4	254	12:45 PM
4	4	4	5	2	0.184	10538	6.6	254	01:34 PM
4	4	4	5	3	0.158	12455	6.6	254	01:37 PM
4	4	4	5	4	0.145	11297	6.6	254	01:40 PM
4	4	4	6	1	0.131	7841	6.6	254	01:43 PM
4	4	4	6	2	0.185	10462	7.0	254	02:34 PM
4	4	4	6	3	0.168	12841	7.9	254	02:42 PM
4	4	4	6	4	0.151	10579	7.9	254	02:46 PM
4	4	5	1	1	0.133	7876	7.9	254	09:13 AM
4	4	5	2	1	0.482	2145	32.2	254	09:16 AM
4	4	5	3	1	0.54	1793	33.5	254	09:19 AM
4	4	5	4	1	0.618	1414	35.8	254	09:22 AM
4	4	5	5	1	0.680	1186	38.1	254	09:57 AM
4	4	5	6	1	0.771	986	37.5	254	10:00 AM
4	4	5	7	1	0.835	834	39.8	254	10:03 AM
5	1	1	1	1	0.32	745	43.7	254	10:06 AM
5	1	1	2	1	0.211	6586	14.1	165	10:55 AM
5	1	1	3	1	0.181	6455	14.1	165	10:58 AM
5	1	1	4	1	0.186	5441	14.1	165	11:00 AM
5	1	2	1	1	0.327	5041	14.1	165	11:03 AM
5	1	2	2	1	0.218	5834	14.6	165	11:57 AM
5	1	2	2	2	0.218	6867	14.6	165	12:00 PM
5	1	2	2	3	0.182	5545	14.6	165	12:01 PM
5	1	2	4	1	0.189	5007	14.6	165	12:04 PM
5	1	3	1	1	0.332	6421	15.5	165	12:55 PM
5	1	3	2	1	0.218	6207	15.5	165	12:58 PM
5	1	3	3	1	0.183	5179	15.5	165	01:01 PM
5	1	3	4	1	0.192	5200	15.5	165	01:04 PM
5	1	4	1	1	0.338	5248	16.8	165	01:54 PM
5	1	4	2	1	0.222	5414	16.8	165	01:58 PM
5	1	4	3	1	0.189	5082	16.8	165	02:01 PM
5	1	4	4	1	0.189	4428	16.8	165	02:04 PM
5	1	5	1	1	0.35	5476	18	165	02:58 PM
5	1	5	2	1	0.219	5809	18	165	03:01 PM
5	1	5	3	1	0.187	4383	18	165	03:04 PM
5	1	5	4	1	0.191	4421	18	165	03:06 PM
5	1	6	1	1	0.353	5048	19.2	165	03:57 PM
5	1	6	2	1	0.233	5255	19.2	165	04:00 PM
5	1	6	3	1	0.192	4834	19.2	165	04:04 PM
5	1	6	4	1	0.199	3834	19.2	165	04:07 PM
5	1	7	1	1	0.372	4497	20.9	165	06:12 AM
5	1	7	2	1	0.229	5338	20.9	165	06:15 AM
5	1	7	3	1	0.196	3531	20.9	165	06:18 AM
5	1	7	4	1	0.208	4221	20.9	165	06:21 AM
5	1	8	1	1	0.379	4117	21.7	165	06:48 AM
5	1	8	2	1	0.234	4455	21.7	165	06:51 AM
5	1	8	3	1	0.2	3317	21.7	165	06:54 AM
5	1	8	4	1	0.205	3426	21.7	165	06:58 AM
5	2	1	1	1	0.378	2421	31.1	165	09:48 AM
5	2	1	2	1	0.257	2248	31.1	165	09:49 AM
5	2	1	3	1	0.224	2048	31.1	165	09:52 AM
5	2	1	4	1	0.233	2028	31.1	165	09:55 AM
5	2	2	1	1	0.366	2179	31.9	165	10:49 AM
5	2	2	2	1	0.255	2490	31.9	165	10:52 AM
5	2	2	3	1	0.244	1483	31.9	165	10:55 AM
5	2	2	4	1	0.241	2055	31.9	165	10:57 AM
5	2	3	1	1	0.421	1772	34.1	165	11:51 AM
5	2	3	2	1	0.269	2138	34.1	165	11:54 AM
5	2	3	3	1	0.247	1400	34.1	165	11:57 AM
5	2	3	4	1	0.251	1821	34.1	165	12:00 PM
5	2	4	1	1	0.465	1255	37.1	165	12:49 PM
5	2	4	2	1	0.285	1690	37.1	165	12:52 PM
5	2	4	3	1	0.266	1103	37.1	165	12:55 PM
5	2	4	4	1	0.273	1331	37.1	165	01:54 PM
5	2	5	1	1	0.488	1034	40.8	165	01:57 PM
5	2	5	2	1	0.313	1214	40.8	165	02:00 PM
5	2	5	3	1	0.282	959	40.8	165	02:01 PM
5	2	5	4	1	0.293	952	40.8	165	02:52 PM
5	2	6	1	1	0.515	888	43.8	165	02:55 PM
5	2	6	2	1	0.317	1152	43.8	165	03:57 PM
5	2	6	3	1	0.304	708	43.8	165	03:58 PM
5	2	6	4	1	0.311	807	43.8	165	04:01 PM
5	2	7	1	1	0.534	750	46.7	165	04:40 AM
5	2	7	2	1	0.342	855	46.7	165	04:43 AM
5	2	7	3	1	0.319	880	46.7	165	04:49 AM
5	2	7	4	1	0.33	641	46.7	165	05:51 AM
5	2	8	1	1	0.538	828	49	165	10:52 AM
5	2	8	2	1	0.364	860	49	165	10:58 AM
5	2	8	3	1	0.333	614	49	165	11:52 AM
5	2	8	4	1	0.341	586	49	165	11:55 AM
5	2	9	1	1	0.564	626	50.7	165	11:58 AM
5	2	9	2	1	0.368	641	50.7	165	12:01 PM
5	2	9	3	1	0.347	538	50.7	165	12:55 PM
5	2	9	4	1	0.354	524	50.7	165	12:58 PM
5	3	1	1	1	0.327	8831	14.6	165	11:00 AM
5	3	1	2	1	0.21	5710	14.6	165	11:52 AM
5	3	1	3	1	0.196	3524	14.6	165	11:55 AM
5	3	1	4	1	0.182	4166	14.6	165	11:58 AM
5	3	2	1	1	0.361	5290	17.3	165	12:04 PM
5	3	2	2	1	0.218	5241	17.3	165	12:52 PM
5	3	2	3	1	0.195	3883	17.3	165	12:55 PM
5	3	2	4	1	0.195	4152	17.3	165	12:57 PM
5	3	3	1	1	0.374	4703	21	165	01:00 PM
5	3	3	2	1	0.227	3689	21	165	01:52 PM
5	3	3	3	1	0.202	2963	21	165	01:55 PM
5	3	3	4	1	0.204	2331	21	165	01:57 PM
5	3	4	1	1	0.389	4421	23.8	165	02:00 PM

5	3	4	2	0.231	4166	23.8	165	02:52 PM
5	3	4	3	0.207	2897	23.8	165	02:55 PM
5	3	4	4	0.209	2800	23.8	165	02:57 PM
5	3	5	1	0.4	3979	25.8	165	03:00 PM
5	3	5	2	0.235	4000	25.8	165	03:49 PM
5	3	5	3	0.207	2759	25.8	165	03:51 PM
5	3	5	4	0.21	2566	25.8	165	03:54 PM
5	3	6	1	0.366	3779	26.9	165	03:55 PM
5	3	6	2	0.231	3603	26.9	165	09:25 AM
5	3	6	3	0.213	2724	26.9	165	09:28 AM
5	3	6	4	0.206	2876	26.9	165	09:30 AM
5	3	7	1	0.366	4117	25.9	165	09:33 AM
5	3	7	2	0.219	4276	25.9	165	09:57 AM
5	3	7	3	0.199	3241	25.9	165	09:58 AM
5	3	7	4	0.197	2786	25.9	165	10:01 AM
5	4	1	1	0.299	13607	1.4	165	10:04 AM
5	4	1	2	0.194	9724	1.4	165	10:55 AM
5	4	1	3	0.188	8076	1.4	165	10:56 AM
5	4	1	4	0.178	9152	1.4	165	11:01 AM
5	4	2	1	0.316	10076	2.6	165	11:03 AM
5	4	2	2	0.204	7834	2.6	165	11:55 AM
5	4	2	3	0.197	7041	2.6	165	11:58 AM
5	4	2	4	0.183	10069	2.6	165	12:01 PM
5	4	3	1	0.337	9593	5.5	165	12:03 PM
5	4	3	2	0.214	9159	5.5	165	12:55 PM
5	4	3	3	0.21	5586	5.5	165	12:58 PM
5	4	3	4	0.192	7059	5.5	165	01:01 PM
5	4	4	1	0.366	8676	8.3	165	01:04 PM
5	4	4	2	0.227	12352	8.3	165	01:55 PM
5	4	4	3	0.22	5648	8.3	165	01:57 PM
5	4	5	1	0.201	7041	8.3	165	02:00 PM
5	4	5	2	0.301	7090	11.8	165	02:03 PM
5	4	5	3	0.24	7710	11.8	165	02:57 PM
5	4	5	4	0.229	5669	11.8	165	02:58 PM
5	4	5	5	0.204	6524	11.8	165	03:01 PM
5	4	6	1	0.368	7007	13.8	165	03:04 PM
5	4	6	2	0.244	6869	13.8	165	03:52 PM
5	4	6	3	0.236	4076	13.8	165	03:54 PM
5	4	6	4	0.205	5007	13.8	165	03:57 PM
5	4	7	1	0.396	6828	14.8	165	03:58 PM
5	4	7	2	0.242	9510	14.8	165	04:00 AM
5	4	7	3	0.232	4593	14.8	165	04:03 AM
5	4	7	4	0.203	4097	14.8	165	04:06 AM
5	4	8	1	0.387	6503	14.4	165	04:09 AM
5	4	8	2	0.243	7166	14.4	165	04:52 AM
5	4	8	3	0.234	4607	14.4	165	04:55 AM
5	4	8	4	0.199	5545	14.4	165	04:57 AM
6	1	1	1	0.245	3455	20.5	203	10:01 AM
6	1	1	2	0.241	3779	20.5	203	10:52 AM
6	1	1	3	0.232	3503	20.5	203	10:55 AM
6	1	1	4	0.256	2952	20.5	203	11:00 AM
6	1	2	1	0.266	2853	21.1	203	11:01 AM
6	1	2	2	0.263	2800	21.1	203	11:52 AM
6	1	2	3	0.231	3041	21.1	203	11:55 AM
6	1	2	4	0.258	2869	21.1	203	11:58 AM
6	1	3	1	0.27	2483	22.5	203	12:01 PM
6	1	3	2	0.248	2903	22.5	203	12:55 PM
6	1	3	3	0.266	2099	22.5	203	12:57 PM
6	1	3	4	0.257	2766	22.5	203	01:00 PM
6	1	4	1	0.259	3007	22.5	203	01:04 PM
6	1	4	2	0.251	2867	22.5	203	01:51 PM
6	1	4	3	0.252	2738	22.5	203	01:54 PM
6	1	4	4	0.27	2656	22.5	203	01:57 PM
6	1	5	1	0.275	2497	23	203	02:00 PM
6	1	5	2	0.253	3179	23	203	02:52 PM
6	1	5	3	0.245	2966	23	203	02:58 PM
6	1	5	4	0.266	2524	23	203	03:01 PM
6	1	6	1	0.269	2752	24.1	203	03:55 PM
6	1	6	2	0.263	2979	24.1	203	03:58 PM
6	1	6	3	0.275	2131	24.1	203	04:01 PM
6	1	6	4	0.278	2621	24.1	203	04:04 PM
6	1	7	1	0.301	2089	25.7	203	07:55 AM
6	1	7	2	0.275	2634	25.7	203	08:00 AM
6	1	7	3	0.253	2848	25.7	203	08:01 AM
6	1	7	4	0.281	2255	25.7	203	08:03 AM
6	1	8	1	0.29	2159	27.4	203	08:55 AM
6	1	8	2	0.286	2483	27.4	203	08:58 AM
6	1	8	3	0.304	1593	27.4	203	09:01 AM
6	1	8	4	0.296	2048	27.4	203	09:03 AM
6	2	1	1	0.269	2172	27.6	203	09:52 AM
6	2	1	2	0.27	2663	27.6	203	09:55 AM
6	2	1	3	0.254	2766	27.6	203	09:58 AM
6	2	1	4	0.272	2366	27.6	203	10:01 AM
6	2	2	1	0.275	2434	28	203	10:49 AM
6	2	2	2	0.268	2841	28	203	10:52 AM
6	2	2	3	0.267	2372	28	203	10:55 AM
6	2	2	4	0.278	2352	28	203	10:58 AM
6	2	3	1	0.285	2297	29.1	203	11:52 AM
6	2	3	2	0.281	2400	29.1	203	11:55 AM
6	2	3	3	0.28	2152	29.1	203	11:58 AM
6	2	3	4	0.299	2055	29.1	203	12:01 PM
6	2	4	1	0.304	2021	31.5	203	12:52 PM
6	2	4	2	0.307	1869	31.5	203	12:55 PM
6	2	4	3	0.305	1738	31.5	203	12:58 PM
6	2	4	4	0.324	1669	31.5	203	01:00 PM
6	2	5	1	0.324	1572	34.3	203	01:54 PM
6	2	5	2	0.325	1738	34.3	203	

6	2	5	3	0.306	1886	34.3	203	02:00 PM
6	2	5	4	0.336	1524	34.3	203	02:03 PM
6	2	6	2	0.349	1434	37	203	02:04 PM
6	2	6	3	0.331	1676	37	203	02:54 PM
6	2	6	4	0.324	1545	37	203	02:57 PM
6	2	7	1	0.36	1214	37	203	03:00 PM
6	2	7	2	0.345	1317	38.4	203	03:03 PM
6	2	7	3	0.345	1421	38.4	203	03:52 PM
6	2	7	4	0.376	917	38.4	203	03:57 PM
6	2	8	1	0.355	1241	38.4	203	04:00 PM
6	2	8	2	0.359	1200	39.7	203	04:01 PM
6	2	8	3	0.358	1228	39.7	203	09:33 AM
6	2	8	4	0.336	1248	39.7	203	09:34 AM
6	2	9	1	0.372	1000	39.7	203	09:37 AM
6	2	9	2	0.367	1172	40.3	203	09:40 AM
6	2	9	3	0.379	1076	40.3	203	09:52 AM
6	2	9	4	0.34	1289	40.3	203	09:55 AM
6	2	1	1	0.362	1152	40.3	203	09:57 AM
6	3	1	2	0.204	7476	10	203	09:58 AM
6	3	1	3	0.209	5078	10	203	10:57 AM
6	3	1	4	0.199	5869	10	203	11:00 AM
6	3	2	1	0.215	4524	10	203	11:01 AM
6	3	2	2	0.215	5117	10.5	203	11:04 AM
6	3	2	3	0.204	5000	10.5	203	12:45 PM
6	3	2	4	0.204	4545	10.5	203	12:48 PM
6	3	3	1	0.216	5386	10.5	203	12:49 PM
6	3	3	2	0.217	4628	12.1	203	12:52 PM
6	3	3	3	0.208	4545	12.1	203	01:01 PM
6	3	3	4	0.204	5883	12.1	203	01:04 PM
6	3	3	5	0.221	4917	12.1	203	01:06 PM
6	3	4	1	0.243	3559	15.7	203	01:09 PM
6	3	4	2	0.23	3945	15.7	203	01:52 PM
6	3	4	3	0.218	4586	15.7	203	01:55 PM
6	3	4	4	0.239	3393	15.7	203	01:57 PM
6	3	5	1	0.234	4241	16.4	203	02:00 PM
6	3	5	2	0.23	3331	16.4	203	02:52 PM
6	3	5	3	0.226	2903	16.4	203	02:54 PM
6	3	5	4	0.24	3186	16.4	203	02:57 PM
6	3	6	1	0.239	2860	17.7	203	03:00 PM
6	3	6	2	0.236	3248	17.7	203	03:49 PM
6	3	6	3	0.214	3814	17.7	203	03:52 PM
6	3	6	4	0.225	3179	17.7	203	03:55 PM
6	3	7	1	0.23	3303	18	203	03:58 PM
6	3	7	2	0.225	2863	18	203	09:04 AM
6	3	7	3	0.212	3821	18	203	09:09 AM
6	3	7	4	0.236	3655	18	203	09:12 AM
6	3	8	1	0.232	2793	18.1	203	09:15 AM
6	3	8	2	0.221	3666	18.1	203	09:55 AM
6	3	8	3	0.218	3676	18.1	203	09:58 AM
6	3	8	4	0.227	3090	18.1	203	10:01 AM
6	4	1	1	0.16	6779	-1.2	203	10:04 AM
6	4	1	2	0.167	8996	-1.2	203	10:54 AM
6	4	1	3	0.16	8531	-1.2	203	10:57 AM
6	4	1	4	0.168	7683	-1.2	203	11:00 AM
6	4	2	1	0.176	7807	-1.2	203	11:03 AM
6	4	2	2	0.175	7193	-1.2	203	11:54 AM
6	4	2	3	0.166	8276	-1.2	203	11:57 AM
6	4	2	4	0.178	7159	-1.2	203	12:00 PM
6	4	3	1	0.197	5517	-0.5	203	12:03 PM
6	4	3	2	0.181	7841	-0.5	203	12:52 PM
6	4	3	3	0.174	7421	-0.5	203	12:55 PM
6	4	3	4	0.182	6655	-0.5	203	12:58 PM
6	4	4	1	0.211	4952	2.2	203	01:01 PM
6	4	4	2	0.193	6021	2.2	203	01:58 PM
6	4	4	3	0.181	6359	2.2	203	02:01 PM
6	4	4	4	0.191	5269	2.2	203	02:04 PM
6	4	5	1	0.212	5007	5	203	02:07 PM
6	4	5	2	0.203	5660	5	203	02:54 PM
6	4	5	3	0.21	4269	5	203	02:57 PM
6	4	5	4	0.213	4772	5	203	03:00 PM
6	4	6	1	0.232	3821	7.8	203	03:52 PM
6	4	6	2	0.215	4979	7.8	203	03:55 PM
6	4	6	3	0.208	4579	7.8	203	03:58 PM
6	4	6	4	0.219	4228	7.8	203	04:01 PM
6	4	7	1	0.224	3828	7.8	203	08:57 AM
6	4	7	2	0.21	4924	7.8	203	09:00 AM
6	4	7	3	0.215	3476	7.8	203	09:03 AM
6	4	7	4	0.211	4814	7.8	203	09:07 AM
6	4	8	1	0.218	4041	7.2	203	09:58 AM
6	4	8	2	0.208	4863	7.2	203	10:03 AM
6	4	8	3	0.21	3952	7.2	203	10:06 AM
6	4	8	4	0.212	4372	7.2	203	10:09 AM
7	1	1	1	0.139	36676	13.5	241	11:01 AM
7	1	1	2	0.142	36614	13.5	241	11:04 AM
7	1	1	3	0.141	32531	13.5	241	11:07 AM
7	1	1	4	0.134	26124	13.5	241	11:10 AM
7	1	2	1	0.149	35621	15.9	241	12:01 PM
7	1	2	2	0.156	32469	15.9	241	12:04 PM
7	1	2	3	0.154	29345	15.9	241	12:09 PM
7	1	2	4	0.144	25098	15.9	241	12:12 PM
7	1	3	1	0.172	27331	17.7	241	12:55 PM
7	1	3	2	0.175	25724	17.7	241	12:58 PM
7	1	3	3	0.169	25000	17.7	241	01:01 PM
7	1	3	4	0.162	21724	17.7	241	01:06 PM
7	1	4	1	0.194	21983	21.4	241	01:58 PM
7	1	4	2	0.195	21628	21.4	241	02:01 PM
7	1	4	3	0.189	19531	21.4	241	

7	1	4	4	0.186	17034	21.4	241	02:04 PM
7	1	5	1	0.202	21834	24.4	241	02:07 PM
7	1	5	2	0.208	19276	24.4	241	02:56 PM
7	1	5	3	0.209	16660	24.4	241	03:01 PM
7	1	5	4	0.202	14469	24.4	241	03:04 PM
7	1	6	1	0.224	17393	27.4	241	03:07 PM
7	1	6	2	0.235	16434	27.4	241	03:54 PM
7	1	6	3	0.23	14400	27.4	241	03:57 PM
7	1	7	1	0.258	13138	27.4	241	04:01 PM
7	1	7	2	0.249	13310	29.8	241	04:03 PM
7	1	7	3	0.252	14110	29.8	241	08:09 AM
7	1	7	4	0.243	11841	29.8	241	08:10 AM
7	1	8	1	0.266	10469	29.8	241	08:13 AM
7	1	8	2	0.267	12517	31.4	241	08:13 AM
7	1	8	3	0.265	12221	31.4	241	08:46 AM
7	1	8	4	0.254	10793	31.4	241	08:49 AM
7	2	1	1	0.238	9710	31.4	241	08:52 AM
7	2	1	2	0.224	10828	30.7	241	08:55 AM
7	2	1	3	0.217	12572	30.7	241	08:57 AM
7	2	1	4	0.217	12662	30.7	241	10:00 AM
7	2	2	1	0.251	12662	30.7	241	10:01 AM
7	2	2	2	0.237	10034	32	241	10:04 AM
7	2	2	3	0.226	10963	32	241	10:57 AM
7	2	2	4	0.222	12145	32	241	11:00 AM
7	2	3	1	0.275	9772	32	241	11:01 AM
7	2	3	2	0.26	9021	34	241	11:04 AM
7	2	3	3	0.254	10090	34	241	11:58 AM
7	2	3	4	0.243	10117	34	241	12:01 PM
7	2	4	1	0.268	8648	34	241	12:03 PM
7	2	4	2	0.26	8188	35	241	12:07 PM
7	2	4	3	0.28	8621	35	241	12:58 PM
7	2	4	4	0.272	8793	35	241	01:00 PM
7	2	5	1	0.352	7352	35	241	01:04 PM
7	2	5	2	0.324	6124	38.8	241	01:07 PM
7	2	5	3	0.319	7007	38.8	241	01:55 PM
7	2	5	4	0.307	7110	38.8	241	01:58 PM
7	2	6	1	0.356	6028	38.8	241	02:01 PM
7	2	6	2	0.357	6338	41.8	241	02:04 PM
7	2	6	3	0.354	6290	41.8	241	02:57 PM
7	2	6	4	0.347	5786	41.8	241	02:58 PM
7	2	7	1	0.425	4950	41.8	241	03:01 PM
7	2	7	2	0.365	4407	44.2	241	03:04 PM
7	2	7	3	0.387	5221	44.2	241	03:52 PM
7	2	7	4	0.37	4800	44.2	241	03:55 PM
7	2	8	1	0.436	4497	44.2	241	03:57 PM
7	2	8	2	0.438	4262	46.4	241	04:00 PM
7	2	8	3	0.421	4138	46.4	241	09:54 AM
7	2	8	4	0.411	4000	46.4	241	09:57 AM
7	2	9	1	0.476	3572	46.4	241	10:00 AM
7	2	9	2	0.453	3531	48.3	241	10:03 AM
7	2	9	3	0.454	3828	48.3	241	10:54 AM
7	2	9	4	0.435	3469	48.3	241	10:54 AM
7	3	1	1	0.14	3131	48.3	241	11:04 AM
7	3	1	2	0.142	47324	7.5	241	11:07 AM
7	3	1	3	0.134	45207	7.5	241	11:55 AM
7	3	1	4	0.126	43552	7.5	241	11:58 AM
7	3	2	1	0.146	39386	7.5	241	12:01 PM
7	3	2	2	0.146	48503	9.6	241	12:04 PM
7	3	2	3	0.141	48503	9.6	241	12:54 PM
7	3	2	4	0.125	39503	9.6	241	12:55 PM
7	3	3	1	0.153	33552	9.6	241	12:58 PM
7	3	3	2	0.15	41462	12.3	241	01:01 PM
7	3	3	3	0.143	32924	12.3	241	01:52 PM
7	3	3	4	0.131	50421	12.3	241	01:55 PM
7	3	4	1	0.150	32034	12.3	241	01:57 PM
7	3	4	2	0.158	43000	13.5	241	02:00 PM
7	3	4	3	0.153	35938	13.5	241	02:55 PM
7	3	4	4	0.134	32241	13.5	241	02:58 PM
7	3	5	1	0.158	37248	13.5	241	03:01 PM
7	3	5	2	0.162	34455	15.2	241	03:04 PM
7	3	5	3	0.151	38945	15.2	241	03:55 PM
7	3	5	4	0.135	30172	15.2	241	03:58 PM
7	3	6	1	0.16	31710	15.2	241	04:01 PM
7	3	6	2	0.158	32055	16.2	241	04:04 PM
7	3	6	3	0.15	35628	16.2	241	08:33 AM
7	3	6	4	0.137	27593	16.2	241	08:36 AM
7	3	7	1	0.158	31779	16.2	241	08:39 AM
7	3	7	2	0.158	32552	16.3	241	08:40 AM
7	3	7	3	0.146	35703	16.3	241	08:55 AM
7	3	7	4	0.139	31350	16.3	241	08:58 AM
7	4	1	1	0.115	39962	16.3	241	09:01 AM
7	4	1	2	0.113	51690	4.2	241	09:04 AM
7	4	1	3	0.114	65283	4.2	241	09:55 AM
7	4	1	4	0.108	67428	4.2	241	09:58 AM
7	4	2	1	0.119	40262	4.2	241	10:01 AM
7	4	2	2	0.119	64690	4.5	241	10:04 AM
7	4	2	3	0.118	63462	4.5	241	10:55 AM
7	4	2	4	0.11	50297	4.5	241	10:58 AM
7	4	3	1	0.121	48860	4.5	241	11:01 AM
7	4	3	2	0.125	51800	5.7	241	11:03 AM
7	4	3	3	0.122	47745	5.7	241	12:01 PM
7	4	3	4	0.117	40090	5.7	241	12:04 PM
7	4	4	1	0.135	41434	5.7	241	12:07 PM
7	4	4	2	0.137	47641	6.3	241	12:09 PM
7	4	4	3	0.133	37814	6.3	241	01:26 PM
7	4	4	4	0.121	50814	6.3	241	01:31 PM
7	4	4	4	0.121	53579	6.3	241	01:34 PM

7	4	5	1	0.136	37731	8	241	01:37 PM
7	4	5	2	0.136	42531	8	241	01:55 PM
7	4	5	3	0.133	46152	8	241	01:58 PM
7	4	5	4	0.102	46434	8	241	02:01 PM
7	4	6	1	0.141	55269	9.7	241	02:03 PM
7	4	6	2	0.142	44014	9.7	241	02:58 PM
7	4	6	3	0.141	42779	9.7	241	03:01 PM
7	4	6	4	0.135	34731	10.2	241	03:03 PM
7	4	7	2	0.147	46221	10.2	241	03:04 PM
7	4	7	3	0.141	35745	10.2	241	03:55 PM
7	4	7	4	0.13	38103	10.2	241	03:57 PM
7	4	8	1	0.146	39517	10.2	241	03:58 PM
7	4	8	2	0.145	42055	11	241	04:01 PM
7	4	8	3	0.14	44221	11	241	09:45 AM
7	4	8	4	0.129	31880	11	241	10:30 AM
7	4	9	1	0.144	36324	11	241	11:30 AM
7	4	9	2	0.145	41867	11.3	241	12:30 PM
7	4	9	3	0.137	44448	11.3	241	01:30 PM
7	4	9	4	0.13	40324	11.3	241	02:30 PM
81	1	1	1	0.348	40331	11.3	191	03:30 PM
81	1	1	2	0.239	4352	26.2	191	8:33
81	1	2	1	0.36	5400	26.8	191	8:46
81	1	2	2	0.252	4469	27.5	191	9:24
81	1	3	1	0.377	4834	28.1	191	9:30
81	1	3	2	0.261	4028	28.7	191	10:30
81	1	4	1	0.433	5145	29.5	191	10:45
81	1	4	2	0.3	3489	31.2	191	11:30
81	1	5	1	0.502	4034	32.5	191	11:42
81	1	5	2	0.338	2503	35.6	191	12:45
81	1	6	1	0.525	2988	35	191	12:48
81	1	6	2	0.361	2214	36.3	191	13:30
81	1	7	2	0.54	2428	37.6	191	13:42
81	1	7	3	0.364	1779	38.9	191	14:30
81	1	8	1	0.559	2441	38.9	191	14:42
81	1	8	2	0.37	1566	40.3	191	15:30
81	1	9	1	0.571	2359	36.8	191	15:42
81	1	9	2	0.389	1503	43.4	191	16:30
81	2	1	1	0.301	1731	41.7	191	16:45
81	2	1	2	0.229	4883	25.3	191	8:00
81	2	2	1	0.306	5289	25.3	191	8:20
81	2	2	2	0.232	4034	25.4	191	9:00
81	2	3	1	0.327	5807	25.8	191	9:18
81	2	3	2	0.255	4280	36	191	10:00
81	2	4	1	0.38	4490	27	191	10:18
81	2	4	2	0.261	2807	31.7	191	12:10
81	2	5	1	0.401	4352	29.7	191	11:14
81	2	5	2	0.281	2883	33.1	191	13:05
81	2	6	1	0.406	3717	30.8	191	12:30
81	2	6	2	0.294	2428	34.8	191	14:00
81	2	7	1	0.413	3710	32.7	191	13:15
81	2	7	2	0.299	2359	36.1	191	15:00
81	2	8	1	0.419	3386	33.9	191	13:45
81	2	8	2	0.311	2283	36.9	191	16:00
81	2	9	1	0.408	2883	35.4	191	14:45
81	2	9	2	0.313	2289	36.8	191	17:00
81	3	1	1	0.261	2876	35.8	191	15:45
81	3	1	2	0.198	7200	16.3	191	8:50
81	3	2	1	0.267	9159	17.2	191	9:00
81	3	2	2	0.213	7255	18.2	191	9:50
81	3	3	1	0.294	8110	18.8	191	10:00
81	3	3	2	0.23	6082	20.9	191	10:50
81	3	4	1	0.32	7282	21	191	11:00
81	3	4	2	0.242	5386	23.8	191	11:50
81	3	5	1	0.337	6883	23.9	191	12:05
81	3	5	2	0.26	5089	28.2	191	12:55
81	3	6	1	0.36	5338	28.7	191	13:08
81	3	6	2	0.277	4082	29.4	191	13:55
81	3	7	1	0.383	4338	29.5	191	14:05
81	3	7	2	0.269	3345	31.9	191	14:55
81	3	8	1	0.364	3972	31.5	191	15:08
81	3	8	2	0.267	2988	32.5	191	15:55
81	3	9	1	0.362	3759	32.8	191	16:05
81	3	9	2	0.28	3055	32.9	191	16:55
81	4	1	1	0.238	3710	32.8	191	17:05
81	4	1	2	0.176	21117	2.1	191	9:00
81	4	2	1	0.24	15262	2.6	191	9:10
81	4	2	2	0.178	18421	5.4	191	10:00
81	4	3	1	0.244	16324	5.7	191	10:10
81	4	3	2	0.176	11869	8.4	191	11:00
81	4	4	1	0.243	14228	8.1	191	11:10
81	4	4	2	0.185	13021	11	191	12:00
81	4	5	1	0.254	13359	11.1	191	12:10
81	4	5	2	0.188	10448	14	191	13:00
81	4	6	1	0.256	11779	13.8	191	1:10
81	4	6	2	0.183	9055	15.5	191	14:00
81	4	7	1	0.252	10862	15.2	191	2:20
81	4	7	2	0.186	9821	16.1	191	15:00
81	4	8	1	0.249	10628	16.5	191	3:15
81	4	8	2	0.186	9441	18	191	16:00
81	4	9	1	0.256	10634	16.4	191	4:06
82	1	1	1	0.315	4083	24.7	88	8:00
82	1	1	2	0.284	3624	25.1	88	8:10
82	1	2	1	0.319	3634	26.1	88	9:00
82	1	2	2	0.286	3503	27	88	9:10
82	1	3	1	0.319	3007	29.2	88	10:00
82	1	3	2	0.305	3124	28.5	88	10:10
82	1	4	1	0.338	2690	30.7	88	11:00

82	1	4	2	0.311	2563	31.3	88	11:10
82	1	5	2	0.337	2090	34.9	88	12:10
82	1	5	1	0.334	1952	35.6	88	12:25
82	1	6	2	0.359	1428	40.9	88	13:10
82	1	7	1	0.341	1469	40.3	88	13:15
82	1	7	2	0.366	1317	42.8	88	14:00
82	1	8	1	0.349	1386	41.7	88	14:10
82	1	8	2	0.367	1317	42.9	88	15:00
82	1	9	1	0.352	1386	41.9	88	15:10
82	1	9	2	0.36	1248	43.8	88	16:00
82	1	9	1	0.357	1317	42.9	88	16:10
82	2	1	1	0.273	4579	22.6	88	8:30
82	2	1	2	0.26	4579	23	88	8:30
82	2	2	1	0.265	4083	24.6	88	9:30
82	2	2	2	0.265	3924	25.3	88	9:30
82	2	3	1	0.28	3007	28.9	88	10:30
82	2	3	2	0.278	3124	28.6	88	10:30
82	2	4	1	0.316	2563	31.6	88	11:30
82	2	4	2	0.285	2503	31.4	88	11:30
82	2	5	1	0.315	1768	37.2	88	12:30
82	2	5	2	0.294	1828	36.8	88	12:30
82	2	6	1	0.33	1469	40.4	88	13:30
82	2	6	2	0.307	1559	30.6	88	13:30
82	2	7	1	0.332	1317	42.8	88	14:30
82	2	7	2	0.314	1317	42.5	88	14:30
82	2	8	1	0.329	1428	41.2	88	15:30
82	2	8	2	0.311	1386	41.6	88	15:30
82	2	9	1	0.319	1469	40.4	88	16:30
82	2	9	2	0.305	1469	40.5	88	16:30
82	3	1	1	0.29	8028	14.6	88	9:20
82	3	1	2	0.269	7745	15.1	88	9:25
82	3	2	1	0.295	6448	18.2	88	10:10
82	3	2	2	0.271	6448	18.1	88	10:15
82	3	3	1	0.285	4945	21.9	88	11:00
82	3	3	2	0.27	5138	21.4	88	11:05
82	3	4	1	0.308	3779	25.8	88	12:00
82	3	4	2	0.262	3924	25.3	88	12:05
82	3	5	1	0.302	2867	29.7	88	13:00
82	3	5	2	0.285	3124	28.8	88	13:05
82	3	6	1	0.294	2414	32.3	88	14:00
82	3	6	2	0.292	2563	31.3	88	14:05
82	3	7	1	0.316	2080	34.9	88	15:00
82	3	7	2	0.3	2241	33.6	88	15:05
82	3	8	1	0.319	2168	34.3	88	16:00
82	3	8	2	0.29	2241	33.7	88	16:05
82	3	9	1	0.304	2563	31.4	88	17:05
82	3	9	2	0.28	2563	31.2	88	17:00
82	4	1	1	0.321	14524	3.9	88	9:30
82	4	1	2	0.275	14897	3.8	88	11:00
82	4	2	1	0.329	10890	9.9	88	11:00
82	4	2	2	0.288	10545	10	88	12:20
82	4	3	1	0.33	8028	14.8	88	12:14
82	4	3	2	0.292	7207	16.1	88	13:00
82	4	4	1	0.326	6448	17.8	88	13:00
82	4	4	2	0.292	6945	18.7	88	14:10
82	4	5	1	0.318	5988	19.1	88	14:00
82	4	5	2	0.294	6945	17.1	88	15:00
82	4	6	1	0.319	6448	17.8	88	15:00
82	4	6	2	0.288	6897	17.5	88	16:00
82	4	7	1	0.312	8028	14.8	88	16:00
82	4	7	2	0.283	7207	16.3	88	9:00
83	1	1	1	0.225	4931	26.1	228	9:00
83	1	1	2	0.254	3968	27	228	10:00
83	1	2	1	0.229	4455	29.3	228	10:15
83	1	2	2	0.27	3303	29.5	228	11:00
83	1	3	1	0.244	3821	30.7	228	11:05
83	1	3	2	0.303	2568	31.4	228	12:00
83	1	4	1	0.276	2855	31.9	228	12:05
83	1	4	2	0.332	2055	32.7	228	13:09
83	1	5	1	0.308	2168	34.1	228	13:18
83	1	5	2	0.363	1510	35.8	228	14:00
83	1	6	1	0.318	2014	35.7	228	14:05
83	1	6	2	0.308	1379	38.7	228	15:00
83	1	7	1	0.325	1924	35.8	228	15:00
83	1	7	2	0.423	1145	42.9	228	15:09
83	1	8	1	0.337	1768	37.4	228	16:00
83	1	8	2	0.403	1228	42.5	228	16:06
83	1	9	1	0.326	1855	37.7	228	16:45
83	1	9	2	0.421	1152	43.3	228	16:51
83	2	1	1	0.19	6352	23.9	228	8:00
83	2	1	2	0.209	5786	23.8	228	8:00
83	2	2	1	0.188	6566	24.3	228	9:00
83	2	2	2	0.214	5414	24.3	228	9:00
83	2	3	1	0.208	5131	25.3	228	10:00
83	2	3	2	0.243	4262	25.9	228	10:00
83	2	4	1	0.223	4331	27.2	228	11:00
83	2	4	2	0.258	3669	27.5	228	11:00
83	2	5	1	0.247	3400	28.6	228	12:00
83	2	5	2	0.298	2545	30.3	228	12:05
83	2	6	1	0.283	2890	32.7	228	13:00
83	2	6	2	0.327	2063	34	228	13:00
83	2	7	1	0.292	2255	34.3	228	14:00
83	2	7	2	0.333	1903	35.8	228	14:00
83	2	8	1	0.294	2138	36.3	228	15:00
83	2	8	2	0.345	1724	36.1	228	15:05
83	2	9	1	0.297	2083	36.9	228	16:00
83	2	9	2	0.347	1860	36.3	228	16:00

83	3	1	1	1	0.150	10966	14.9	228	8:58
83	3	1	2	1	0.165	8669	14.9	228	9:02
83	3	2	2	2	0.161	9731	15.6	228	10:02
83	3	2	2	1	0.164	7924	16	228	10:05
83	3	3	1	2	0.166	8862	16.2	228	11:00
83	3	3	1	1	0.197	6883	19.4	228	11:04
83	3	4	1	2	0.177	7462	20.6	228	12:00
83	3	4	1	1	0.216	5267	21.6	228	12:04
83	3	5	1	2	0.182	6610	21.1	228	13:00
83	3	5	1	1	0.225	4772	23.6	228	13:05
83	3	6	1	2	0.191	6048	22.4	228	14:00
83	3	6	1	1	0.235	4262	26.1	228	14:05
83	3	7	1	2	0.205	5089	23.5	228	15:00
83	3	7	1	1	0.245	3821	27.7	228	15:03
83	3	8	1	2	0.202	5034	25.7	228	16:05
83	3	8	1	1	0.241	3910	28.5	228	16:10
83	3	9	1	2	0.207	4655	26.4	228	16:45
83	3	9	1	1	0.228	4214	29	228	16:50
83	4	1	1	1	0.145	12490	10.7	228	10:38
83	4	1	2	1	0.162	10221	10.5	228	10:50
83	4	2	1	1	0.146	11363	12	228	11:30
83	4	2	2	1	0.165	9214	11.9	228	11:40
83	4	3	1	1	0.149	10476	13.4	228	12:30
83	4	3	2	1	0.171	8490	14.5	228	12:40
83	4	4	1	2	0.149	10462	14.4	228	13:30
83	4	4	2	1	0.175	7814	15.9	228	13:40
83	4	5	1	1	0.152	9697	15	228	14:30
83	4	5	2	1	0.176	7786	17.1	228	14:40
83	4	6	1	1	0.155	9683	14.7	228	15:30
83	4	6	2	1	0.171	8200	16.8	228	15:40
83	4	7	1	2	0.151	10117	14.7	228	16:30
83	4	7	2	1	0.168	8524	15.5	228	16:40
84	1	1	1	1	0.276	6831	21	140	8:04
84	1	1	2	1	0.29	7434	21.1	140	8:02
84	1	2	1	2	0.27	7359	21.3	140	9:00
84	1	2	2	2	0.291	6652	21.6	140	9:04
84	1	3	1	2	0.26	5983	22.2	140	10:00
84	1	3	2	1	0.299	6182	22.6	140	10:04
84	1	4	1	2	0.287	5048	25.5	140	11:00
84	1	4	2	1	0.314	5252	25.9	140	11:05
84	1	5	1	2	0.306	3955	29.6	140	12:00
84	1	5	2	1	0.325	4697	29.9	140	12:05
84	1	6	1	1	0.311	3786	30.9	140	13:00
84	1	6	2	1	0.35	3752	30.5	140	12:53
84	1	7	1	2	0.322	3245	35.5	140	14:02
84	1	7	2	1	0.375	2879	36.2	140	14:05
84	1	8	1	2	0.322	3186	35.1	140	15:00
84	1	8	2	1	0.367	2986	35.5	140	15:05
84	1	9	1	2	0.331	2848	36.5	140	16:02
84	1	9	2	1	0.369	2821	36.9	140	16:05
84	2	1	1	1	0.314	3782	27.4	140	8:34
84	2	1	2	1	0.333	4386	28.3	140	8:05
84	2	2	1	1	0.317	3445	29.9	140	9:40
84	2	2	2	2	0.331	4707	28.1	140	9:11
84	2	3	1	1	0.322	3203	32.6	140	10:30
84	2	3	2	1	0.34	4148	30.4	140	10:00
84	2	4	1	1	0.339	2707	36.4	140	11:30
84	2	4	2	1	0.365	3428	34.9	140	11:00
84	2	5	1	2	0.359	2028	40.3	140	12:30
84	2	5	2	1	0.383	2786	38.7	140	12:00
84	2	6	1	1	0.363	1970	42	140	13:30
84	2	6	2	1	0.367	2224	41.1	140	13:00
84	2	7	1	2	0.366	1880	44.7	140	14:20
84	2	7	2	1	0.41	1955	42.4	140	14:00
84	2	8	1	2	0.373	1617	45.2	140	15:25
84	2	8	2	1	0.423	1641	45	140	15:15
84	2	9	1	2	0.377	1462	43.6	140	16:22
84	2	9	2	1	0.417	1669	43.5	140	16:15
84	3	1	1	1	0.285	6421	21.1	140	7:50
84	3	1	2	1	0.287	6652	21.1	140	8:05
84	3	2	1	2	0.279	6038	21.1	140	8:30
84	3	2	2	2	0.268	5883	21.1	140	8:40
84	3	3	1	1	0.276	5387	21.6	140	9:30
84	3	3	2	1	0.29	5407	21.7	140	9:45
84	3	4	1	1	0.263	4986	22.5	140	10:30
84	3	4	2	1	0.285	5293	22.3	140	10:40
84	3	5	1	2	0.29	4655	23.5	140	11:30
84	3	5	2	1	0.308	4776	24.4	140	11:40
84	3	6	1	1	0.3	3617	28.1	140	12:30
84	3	6	2	1	0.322	4245	28.6	140	12:40
84	3	7	1	2	0.323	3434	30.2	140	13:30
84	3	7	2	1	0.34	3741	31.1	140	13:40
84	3	8	1	2	0.324	2955	31.6	140	14:30
84	3	8	2	1	0.34	3583	32.2	140	14:40
84	3	9	1	1	0.33	2638	31.1	140	15:30
84	4	1	1	1	0.345	3345	32.4	140	15:40
84	4	1	2	1	0.267	13141	3.6	140	8:15
84	4	2	1	2	0.284	14641	1.3	140	8:25
84	4	2	2	1	0.261	12755	6.2	140	9:00
84	4	3	1	1	0.265	14376	5	140	9:10
84	4	3	2	1	0.260	12021	13.6	140	10:00
84	4	3	3	1	0.264	12731	12.1	140	10:10
84	4	4	1	1	0.264	10928	15.6	140	11:00
84	4	4	2	1	0.27	11979	15	140	11:10
84	4	4	3	1	0.266	10214	17.5	140	12:00
84	4	4	4	1	0.277	9976	18	140	12:10
84	4	5	1	2	0.265	9079	18.6	140	13:05

84	4	6	2	0.284	8934	19.5	140	13:10
84	4	7	1	0.266	7852	17.3	140	14:02
84	4	7	2	0.285	8841	17.5	140	14:13
84	4	8	1	0.282	8300	16.2	140	15:03
84	4	8	2	0.277	8797	16	140	15:12
84	4	9	1	0.284	8238	15.1	140	16:02
84	4	9	2	0.265	9731	15	140	16:09

Legend:

i = site id [1= Pitt, 2= Carteret, 3= New Hanover, 4= Durham, 5= Polk, 6= Buncombe, 7= Wilkes,

81= US421(sec13) Siler City, 82= US421(sec 17), 83= US421(sec20), 84= US70 Clayton]

j = season id [1= Spring_Apr 95, 2= Summer_Jun 95, 3= Fall_Nov 94, 4= Winter_Jan 95;

for 92/93 data, 1= May/Jun93, 2= Sep92, 3= Oct92, 4= Jan/Feb93].

k = session id [1= first FWD test session of the day (1 session consists of 4 stations), ...10]

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